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Taking Stock

THE END of the year is always a good time to stop and take inventory, to gage what has been accomplished in the past, and, in light of that past, to set new goals for the future.

This, then, is a report to our readers and contributors of the progress made since NUCLEONICS' first issue, September, 1947.

In Volume 1, Number 1, NUCLEONICS was stated to be a journal that would bring to readers a monthly symposium on the applications of nuclear physics. For contributors it would provide a meeting place for the exchange of ideas among engineers, physicists, chemists, life scientists and teachers. NUCLEONICS was to be an international clearing house for the announcement of new applications and techniques of nuclear energy.

It was also pointed out that the final responsibility for NUCLEONICS' doing full justice to its field lay with the contributors who supply the raw material out of which the journal is made and with the readers who supply the funds. At the outset it was decided neither to solicit nor to accept advertising until a clearer picture could be obtained of the course to be followed by the new paper. The pocketbooks of the publisher and the readers, therefore, were the sole resources with which to produce the finished product.

It was further stated in the September, 1947, issue that all revenue in excess of out-of-pocket expenses would be plowed back into the journal for its improvement.

NUCLEONICS has now placed in its readers' hands sixteen regular issues totaling almost 1,600 pages of editorial matter. In addition it paid its readers a dividend, in 1948, in the form of a special 13th Summary Issue, containing over 100 pages of information compiled by the Nuclear Data Committee, Oak Ridge National Laboratory.

Whether or not the editorial content so far has lived up to the original and continuing promises must be left to the readers to decide. Despite tightening security on certain subjects and the dearth of publishable information on other subjects, the editors feel that a representative job has been done. They believe that with the experience gained and the friends made, a

better job can be done in the future. One measure of success in the publishing field is the rate at which readers renew their subscriptions, and to date NUCLEONICS holds up its head rather proudly in the McGraw-Hill family. Its renewal rate is neither the worst nor the best; it lies very near the house average. At present the monthly subscription list hovers very close to 6,000.

So much for the past. What of the future?

In May, 1948, NUCLEONICS began to publish advertising. In the face of constantly increasing production costs, factors over which neither publisher nor editor has control, the revenue from advertising plus the revenue from new and renewing subscribers has kept the profit and loss figure on an even keel. At the year-end it was impossible to state definitely whether there would be a small profit or a small loss, so near the break-even line were the operations. However, without advertising and the splendid support of the subscribers, the picture would be quite different.

The publisher now believes an important promised step can be taken. With this issue the domestic subscription rate has been dropped to $10. At a time when the scientific and engineering societies are forced to reduce their publication budgets or to increase their members' dues, this is a bold and perhaps risky step.

The editors realize that many facets of the nuclear field are as yet untouched in the literature and that great responsibility rests on the editors to dig out and to publish such data as are obtainable. Readers, as well as editors, understand that national security plays more of a role in this field than in any other in America today. However, a recent report made for the Atomic Energy Commission has shown that there is a vast amount of information which has not yet been published and which is declassifiable.

Thus, in 1949, it is hoped that greater space will be devoted to such subjects as techniques and instruments used in nuclear research, fundamentals and technology of nuclear reactors and their control mechanisms, accelerators of fundamental particles, and means for evaluating the effects of radiation. In a new field like nucleonics the experimental techniques undergo daily change. To act effectively as a clearing ground for information on such work, the editors pledge that greater effort will be made in this direction. It is also realized that a tremendous educational job must be done in the nuclear field, not only in the universities but in the secondary schools—to provide more scientists and engineers for the future—and in the great industrial laboratories where the work of the scientists is brought closer to everyday life.

In addition to the "reviews," which have been an important part of NUCLEONICS' monthly editorial fare, its editors will welcome ideas which will help in the educational program, or on new techniques, or on the economics involved—in fact suggestions for articles dealing with any aspect of this new and rather exciting field will receive warm welcome in the editorial office.

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URANIUM HYDRIDE—I

PREPARATION, COMPOSITION and PHYSICAL PROPERTIES*

First of a series of three papers discussing the studies carried out at the Ames laboratory following preparation of uranium hydride from the massive metal for the first time early in 1943

BY

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Soon after large-scale production of massive uranium of high purity was started (*1*), investigations of the chemical properties of the metal were undertaken. Studies of uranium hydride were begun in the Iowa State College laboratories early in 1943 (when it was prepared for the first time from the massive metal) and were continued through 1945.

In 1912, Sieverts and Bergner (*2*), while investigating the solubility of helium and argon in a number of metals at elevated temperatures, treated some crude uranium powder with these gases and with hydrogen. They noted that at 1100° and one atmosphere, 100 g of the impure metal absorbed 1.6 mg of hydrogen. The only other information on the action of hydrogen on uranium in the literature prior to the existence of the Manhattan Project is in patents issued to Driggs (*3*) in 1931, which described a general method of preparing metal hydrides. According to this source, uranium hydride was formed when the metal, a powder prepared electrolytically and containing considerable oxide, was heated in hydrogen to 200–225°. A dissociation pressure-temperature curve was given which has proved to be in reasonable agreement with the data presented in this paper. Driggs recognized that the reaction of uranium with hydrogen was exothermic. The patent described no chemical or other physical properties of the hydride. The inadvertent preparation of uranium hydride was reported early on the Manhattan Project when uranium metal was handled in a hydrogen atmosphere (*4*).

Formation of Uranium Hydride

Preparation of uranium hydride from hydrogen and uranium. It was observed that when massive uranium was heated in hydrogen the gas was rapidly absorbed when the temperature reached 250°, converting the metal to a fine, black, pyrophoric powder (*5*, *6*). Fur-

* This paper is based on work done for the Plutonium Project of the Manhattan District in 1943–44 and was first reported in Plutonium Project Reports CC-580, CC-587, CC-858, CC-1059, CC-1063, CC-1091, CC-1201, CC-1212, and CC-1524.

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ther studies disclosed that uranium turnings or powder, as well as large massive lumps, reacted smoothly with hydrogen at temperatures between 250° and 350°, with the formation of the fine, black or dark gray powder, uranium hydride. Close examination revealed a few small particles distributed throughout the powder; these were presumably inclusions of impurities present in the uranium employed. When the oxide layer was not removed from the uranium metal prior to the hydrogen treatment, the initiation of the reaction was delayed a short time. The presence of small amounts of oxygen in the hydrogen used also caused a delay before the reaction began, but this was remedied by purification of the hydrogen. At 250°, 100 g of cleaned uranium turnings required 25–30 minutes for complete conversion to the hydride, while a single massive lump of the same weight required 90 to 120 minutes. Uranium containing a relatively small proportion of an alloying metal was also converted to a powder by the action of hydrogen.

The hydride prepared from deuterium was formed in an exactly analogous manner. Uranium deuteride was indistinguishable from the ordinary hydride in appearance.

Thermal decomposition of uranium hydride. By heating uranium hydride samples under vacuum, hydrogen was evolved and finely subdivided uranium was produced. The nature of the powdered uranium formed depended upon the temperature employed in the decomposition: At 250°, the decomposition was slow, and the metal was a loose black powder, while at 450° the metal was semi-sintered, but could be broken up by grinding in an inert atmosphere. The powdered uranium prepared by the decomposition of the hydride was exceedingly reactive; it reacted with hydrogen at room temperature, with the generation of heat.

Other methods for formation of uranium hydride. Investigations at pressures up to 126 atm showed that the reaction of hydrogen with uranium began at lower temperatures as the pressure was increased. At 70 atm the reaction began at 150°; at 126 atm, it began at 130°.

Uranium immersed in an inert solvent (mineral oil) reacted with hydrogen only very slowly at 250°, when the gas was introduced at atmospheric pressure. The low rate of reaction was attributed to the slight solubility of hydrogen in the solvent at 250°, and to the manner in which the mineral oil caused the hydride to adhere to the metal, forming a protective coating.

Uranium hydride was also produced by the action of steam on uranium at 250°; uranium dioxide was formed simultaneously.

Treatment of lumps of uranium with tetralin and with decalin at 210–270° for several days caused 3–10% of the metal to disintegrate, forming a black powder. Thermochemical calculations showed that dehydrogenation of the organic compounds to naphthalene was favored, with the accompanying formation of uranium hydride.

Purification and preparation of hydrogen and deuterium. Rigorous purification of hydrogen was achieved by passing it over powdered uranium (made by the thermal decomposition of the hydride) at 700–750° (*6*). The generation of hydrogen or deuter um by thermal decomposition of uranium hydride or deuteride afforded a convenient laboratory source and reservoir of the pure gas, free even of the noble gases (*7*). It was further observed that water could be readily and quantitatively reduced to hydrogen by passing steam over uranium turnings at 600–700°. This was especially useful for the preparation of deuterium from heavy water, the reaction being

$$2D_2O + U \rightarrow UO_2 + 2D_2$$

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The deuterium was then collected in a second vessel containing uranium at 250°, in which flask uranium deuteride was formed. The gas was driven off when needed by raising the temperature and/or reducing the pressure.

Composition of Uranium Hydride

Analysis. The hydrogen-to-uranium ratio of uranium hydride was found by investigators at Battelle Institute (*8*) to be slightly less than three by measurement of the amount of hydrogen evolved on thermal decomposition. Determinations of the ratio were then made at Ames by these five methods: (*a*) weight gain on conversion of uranium to its hydride, (*b*) weight loss on decomposition, (*c*) volume of hydrogen absorbed on formation, (*d*) volume of hydrogen evolved on decomposition, and (*e*) combustion of the hydride, the water formed being weighed. The hydrogen used in these experiments was generated by the decomposition of uranium hydride. In experiments (*a*) and (*b*), the weight changes were not large, and errors were the highest. In experiments (*c*) and (*d*), the hydrogen volumes were measured over water or mercury. The uranium hydride analyzed was prepared by the action of hydrogen on uranium turnings at 250° or on powder at room temperature. In the combustion work (*e*), the uranium hydride was cooled to room temperature in hydrogen, and the apparatus flushed with argon before oxygen was admitted. A heated tube of cupric oxide was employed to convert the small amounts of hydrogen liberated to water. Errors in the combustion analysis were estimated to be $\pm 0.8\%$.

The results of the above analyses, expressed as the H/U ratio, were: method (*a*) 3.04, 3.05, 2.97, and 3.02; method (*b*) 2.95; method (*c*) 2.92; method (*d*) 2.91 and 2.96; method (*e*) 2.94, 2.96, 2.96, and 2.95. It is seen that the ratio is about 2.96 or 2.97, which is less than 3.00 by an amount not entirely ascribable to experimental errors.

Formula of uranium hydride. Since hydrogen was known not to react with uranium when the latter is a component of an intermetallic or other compound, and since quite complete analyses had been made of the uranium used, it proved possible to calculate the effect of impurities on the composition of the hydride. Table 1 gives the most abundant impurities in the uranium used, the compounds as which the contaminating elements are most likely present, and the amounts.

Thus a total of 10070 ppm or 1.0% of the samples consisted of various uranium compounds which could not combine with hydrogen. If each available uranium atom combined with three hydrogen atoms, the over-all hydrogen-to-uranium ratio would be 1% less than 3, namely 2.97. Since 2.96 or 2.97 is the determined ratio, it is evident that the formula of pure uranium hydride is UH_3. Analyses of uranium hydride formed under hydrogen pressures of up to 2000 psi also gave a hydrogen-to-uranium ratio of 3.0 (*9*).

Physical and Thermodynamic Properties of Uranium Hydride

Physical state. The uranium hydride prepared at atmospheric pressure appeared as a very fine black or brownish-gray powder. In an inert atmosphere the particles could easily be passed through a 400-mesh sieve. The specimens prepared under high pressure (126 atm) were much coarser, and contained what appeared to be fibrous crystals, some as long as 6 mm.

The bulk density of uranium hydride was found to be 3.4 g/cc, while the particle density, measured by immersion in hexane, was roughly 11.4 g/cc. More accurate determinations of the particle density, using a helium densitometer similar to that described by

Schumb and Rittner (*10*) gave 10.95 ± 0.10 g/cc. Similar measurements with uranium deuteride gave the particle density as 11.20 ± 0.10 g/cc. These values compare favorably with the X-ray densities obtained by Rundle (*11*), namely, 10.92 g/cc for the hydride and 11.11 g/cc for the deuteride. It is interesting to note that the density of the hydrogen alone in uranium hydride (0.14 g/cc) is greater than the density of liquid hydrogen itself (approximately 0.07 g/cc) by a factor of two.

The X-ray diffraction data (*11*) disclosed the lattice of uranium hydride as cubic, wholly unrelated to that of any of the three forms of uranium metal. The lattice constant of uranium hydride was found to be 6.631 A.U., slightly larger than that of the deuteride, 6.620 A.U.

When uranium hydride powder was compressed at pressures up to 22,600 atm, it formed blocks of metallic appearance with densities up to 8.7 g/cc. The coarse type of hydride prepared at 126 atm could be compressed into blocks of greater density than those from the ordinary form prepared at atmospheric pressure.

Rough measurements of the electrical conductivity of the loosely packed hydride showed it to be of the same order of magnitude as that of the powdered metal (*5*). The hydride was packed between two platinum electrodes by jolting, and the resistance was measured; it was then thermally decomposed, and the resistance of the metal remaining was measured. The average values were 3.8 and 5.5 ohms, respectively, indicating the metallic character of the hydride.

A series of measurements of the densitites of uranium-uranium hydride and uranium-uranium deuteride mixtures was made using the helium densitometer, in order to detect any deviation from linearity in the density-composition relationships. A known mass of uranium was converted to the hydride or deuteride, and its volume then measured periodically on stepwise decomposition, and again on stepwise re-formation. The results are given in Table 2. Plots of the data showed that in both cases the volume was a linear function of the composition within the limits of experimental error (±1.0%).

TABLE 1
Impurities in Uranium

Impurity	*Ppm of impurity*	*Present as*	*Ppm of compound*
C	300	UC	6100
Fe	60	U_6Fe	1550
O	80	UO	1240
N	30	UN	530
Si	50	USi	470
Mn	5	U_6Mn	130
F	10	UF_3	50
			10070

Dissociation pressure-composition isotherms and related data. The preliminary measurements of the dissociation pressure of uranium hydride were erratic because of the unexpectedly long period of time required to establish equilibrium. At constant temperature uranium metal prepared by decomposition of the hydride took on hydrogen rapidly at the start, but on approaching the equilibrium value the pressure changed very slowly, requiring several days to become constant. Although some measurements were made after the expiration of a short arbitrary length of time, only equilibrium values are reported here. Boiling mercury was employed extensively as a constant temperature medium (357°), although other substances were also used.

Samples of uranium hydride maintained at 357° by a bath of mercury vapor in several sets of apparatus were decomposed stepwise by withdrawing measured volumes of hydrogen, thus permitting the calculation of the composition of the U-UH_3 mixture remaining. Following each withdrawal, the

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TABLE 2

Volume of U-UH_3 and U-UD_3 Mixtures

Uranium = 42.195 g

Uranium-uranium hydride		*Uranium-uranium deuteride*	
Composition mol % UH_3	*Volume* cc	*Composition* mol % UD_3	*Volume* cc
0	2.21	0	2.21
7.1	2.32	2.4	2.24
11.5	2.43	11.9	2.41
30.5	2.68	24.2	2.59
35.2	2.78	35.5	2.73
65.2	3.27	53.5	3.07
66.6	3.27	56.5	3.08
89.8	3.67	80.3	3.53
90.5	3.72	93.5	3.75
100.	3.88	100.	3.85

pressure was allowed to become constant (requiring about two days). This was repeated until complete decomposition was achieved. Known volumes of hydrogen were then admitted periodically, and the equilibrium values upon formation of the hydride were recorded. The data are given in Table 3, and are plotted in Fig. 1, giving the 357° isotherm. The higher curve (from data taken during formation) has a plateau from 3 to 97 mol % UH_3, and is reminiscent of the behavior due to compound formation such as in the palladium-hydrogen system, investigated by Gillespie and Hall (*12*). The lower curve (from data taken during decomposition) also has a flat portion,

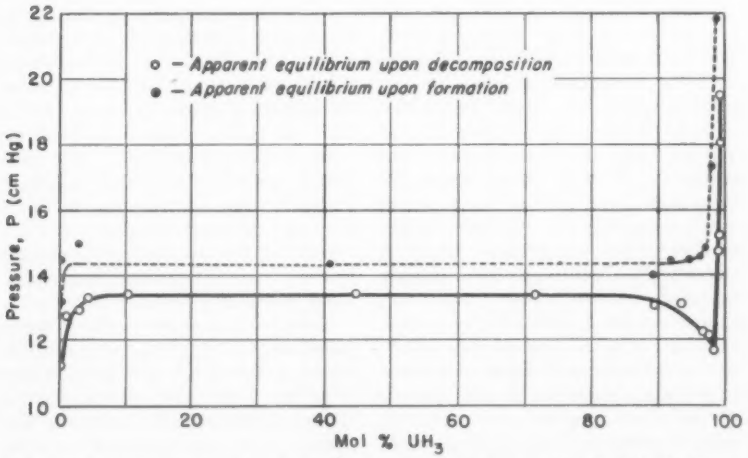

FIG. 1. Pressure-composition isotherm for the uranium-uranium hydride-hydrogen system at 357° C

which is about 10 mm below the upper curve, but its most outstanding feature is a pronounced dip in the 90–98 mol % UH_3 region. This dip is apparently real and not due to lack of equilibrium; one sample of 98 mol % UH_3 was maintained at 357° for two weeks without the pressure deviating from the value shown in the dip of the curve (118 mm). The existence of a dip in the isotherm has been checked by several independent measurements. An X-ray pattern of the material in this composition range showed the diffraction lines of U and UH_3 only, with no change in the lattice constants. There are meager data which indicate a similar dip in the 307° isotherm. No adequate explanation of this unexampled behavior has been advanced. The uranium-hydrogen system is seen to be quite different in nature from the palladium-hydrogen system.

Another unexplained phenomenon observed with this system was the abnormally high pressure produced (sometimes almost twice the equilibrium pressure) when a cooled U-UH_3 sample was heated to a given temperature. The pressure only very slowly fell to a value approaching the equilibrium pressure, *i.e.*, to a pressure corresponding to the upper curve in Fig. 1.

Dissociation pressure-temperature studies were made by heating partially decomposed uranium hydride and deuteride samples in flasks immersed side by side in a low-melting salt bath. When accurate equilibrium values were determined, the bulbs holding the hydride samples were maintained at constant temperature in the vapor of boiling sulfur (444°), mercury (357°), or benzophenone (307°) for several days. The dissociation pressure at 357° corresponds to the plateau of the lower curve in Fig. 1. The data are given in Table 4, and plotted in Fig. 2 (logarithm of the pressure against the reciprocal of the temperature). The data recorded during heating the hydride and deuteride samples simultaneously in a salt bath showed that the deuteride dissociation pressure was about 1.4 times that of hydride for all temperatures studied;

TABLE 3

Equilibrium Pressure of Hydrogen for Various U-UH_3 Compositions at 357°

Pressure by decomposition of UH_3	
Composition mol % UH_3	*Pressure* mm of Hg
99.8	204
99.5	195
99.3	152
99.0	147
98.1	117
98.0	118
97.5	121
97.4	121
96.4	122
96.4	122
93.3	131
92.8	131
89.8	130
89.5	130
71.3	134
44.5	134
10.1	134
4.1	133
3.0	129
1.0	127
0.1	113

Pressure by formation of UH_3	
Composition mol % UH_3	*Pressure* mm of Hg
98.6	237
98.1	173
96.8	148
96.0	145
94.5	144
91.6	144
89.0	139
40.8	143
3.2	149
0.15	132
0.10	127
0.10	144
0.02	114

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TABLE 4
Equilibrium Dissociation Pressure of Uranium Hydride and Deuteride

	Temperature °C	*Pressure mm*
UH_3	307	32.5
	357	134
	444	1010
UD_3	357	186

hence the two curves were drawn parallel. The equations for the two curves in Fig. 2, giving the dissociation pressures of the hydride and deuteride as a function of temperature, are (p in mm of Hg and T in degrees absolute):

For UH_3, $\log p = \frac{-4500}{T} + 9.28$

and for UD_3, $\log p = \frac{-4500}{T} + 9.43.$

The heat of formation of uranium hydride, according to the equation

$$U + \tfrac{3}{2}H_2 \rightarrow UH_3$$

was calculated from the van't Hoff reaction isochore,

$$\frac{d \ln k}{dT} = \frac{\Delta H}{RT^2}, \quad \text{where} \quad k = p^{-\frac{3}{2}}$$

and the dissociation pressure was derived as a function of the temperature from the above equations. This gave $\Delta H = -30.8$ kcal for both the hydride and the deuteride. This value was checked for the hydride by direct determinations, which gave the values $\Delta H = -30.5, -30.7, -30.5$, and -30.0 kcal, averaging -30.4 kcal per mol.

An experiment was designed to determine whether hydrogen would transfer isothermally from uranium hydride to uranium. Two small bulbs, one charged with the hydride and the other with uranium powdered by decomposition of the hydride at 300° under vacuum, were connected and immersed in a molten salt bath at 325°. After 10 hours the bulb initially containing powdered metal was opened to a vacuum system; all of the hydrogen present could be accounted for by the volume of the bulb assuming a hydrogen pressure equal to the dissociation pressure of the hydride at 325°. The experiment was repeated at 300°, 288°, and 269°, with the same result.

Kinetics of formation and hydrogen-deuterium separations. Only a few measurements were made on the reaction kinetics of uranium hydride formation, but some generalizations concerning the rate and kinetics are presented below.

(a) Under atmospheric pressure, the rate of reaction of purified hydrogen with massive uranium was found to be greatest at 230 to 260°, and decreased with reaction temperatures above 260°. With massive metal, once the reaction was begun at 230-260°, it continued even when the temperature was lowered to 150°; this was probably attributable

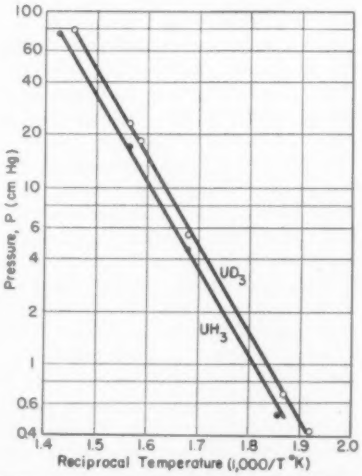

FIG. 2. Decomposition pressures of uranium hydride and deuteride as a function of temperature

to local heating due to the exothermic reaction. With large quantities of powdered uranium, the reaction rate was limited by the rate of heat conduction from the reacting mass.

(b) The reaction rate at any temperature was increased by raising the hydrogen pressure.

(c) Uranium powdered by decomposing the hydride at 400° or below reacted rapidly with hydrogen at room temperature, fairly rapidly at the temperature of solid carbon dioxide, and not at all at the temperature of liquid nitrogen.

(d) At 357°, the reaction rate of deuterium with powdered uranium was about one fourth as great as that of hydrogen. At dry-ice temperatures, the two rates were about equal.

(e) A brief study of the reaction rate at 357° was made by following the rate of decrease of the hydrogen pressure as the gas reacted with powdered uranium. It was found that the initial rate of decrease of hydrogen pressure depended on the initial pressure of the hydrogen according to the equation

$$-\frac{dp}{dt} = c(p - a)^{3/2}$$

where dp/dt is the rate of pressure change, p the pressure, a the initial hydrogen pressure (the dissociation pressure at 357°, 134 mm), and c an empirical constant. The evidence that c is a constant over the pressure range 250 to 665 mm is given in Table 5. No theoretical significance has been attached to the above relationship, nor have the effects of different temperatures on it been ascertained.

When it was discovered that the dissociation pressure of uranium deuteride was about 1.4 times as great as that of the hydride, and that the rate of reaction of deuterium with uranium was about one fourth that of hydrogen in the range of 300–400°, it became evident that a scheme for the separation of the isotopes of hydrogen was possible. It was of interest first to determine whether deuterium in the gas phase would exchange with hydrogen as uranium hydride in the solid phase. An experiment was conducted with a small amount of uranium hydride at 300°; an amount of deuterium equivalent to the hydrogen of the hydride was introduced into the gaseous phase. After five minutes, a sample of the gas was removed and analyzed, and was found to have a composition of 50% hydrogen and 50% deuterium, showing a rapid exchange. Analyses were made using a gas-density balance similar to that described by Stock and Ritter (*13*).

TABLE 5
Evaluation of Rate Constant, c, at 357°

$-\frac{dp}{dt}$, mm/min	p, mm	$p - a$, mm	$c \times 10^5$
10	250	116	6.9
50	350	216	7.3
100	400	266	8.7
200	490	356	8.4
300	565	431	5.9
500	665	531	7.7

A series of experiments was performed in which various mixtures of uranium hydride and deuteride were fractionally decomposed. In one experiment, samples of gas were withdrawn periodically from a mixture containing 19.8 mol % uranium deuteride at 410°. The first fraction contained 23.2% deuterium and the tenth fraction 16.8%, corresponding to the relatively low molar separation factor of 1.2. Another experiment consisted of passing ordinary hydrogen through a 3-meter column of powdered uranium, insulated and heated electrically to 250°, but no measurable enrichment of deuterium in the first fraction could be detected. No efficient technique of

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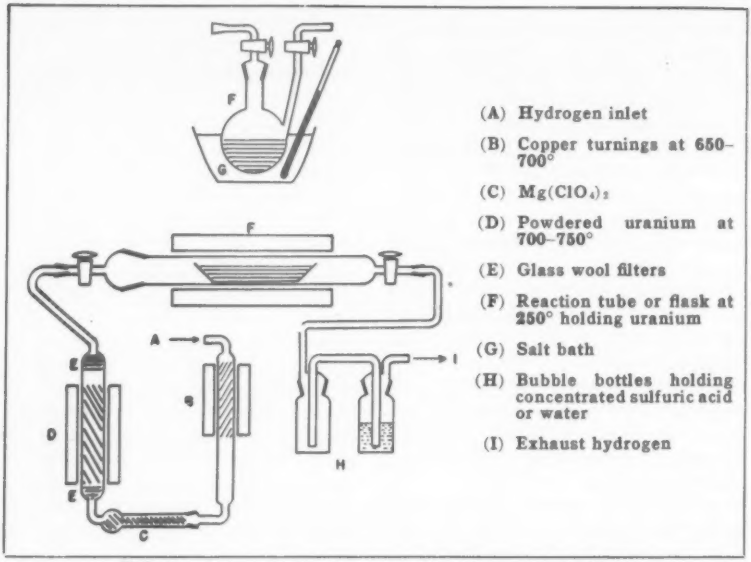
(A) Hydrogen inlet
(B) Copper turnings at 650–700°
(C) $Mg(ClO_4)_2$
(D) Powdered uranium at 700–750°
(E) Glass wool filters
(F) Reaction tube or flask at 250° holding uranium
(G) Salt bath
(H) Bubble bottles holding concentrated sulfuric acid or water
(I) Exhaust hydrogen

FIG. 3. Apparatus for the preparation of uranium hydride

separating deuterium from hydrogen was found.

Experimental

Preparation of uranium hydride. Massive uranium, either as turnings or lumps, was cleaned of the oxide coating with dilute nitric acid, washed, and dried. The hydrogen was pre-purified in the classical manner by passing over copper at 650–700° and drying with anhydrous magnesium perchlorate; it was further purified by passing through powdered uranium at 700–750°, prepared *in situ*.

Conversion to the hydride was carried out in several types of apparatus, two of which are shown in Fig. 3. An electrically heated tube, or a flask heated by a furnace or a low-melting, nitrate-nitrite salt bath (*14*), was employed, large enough to allow for expansion on hydride formation. Air was flushed from the apparatus with hydrogen, and the temperature raised to 250°. The reaction was complete when, on shutting off the hydrogen, liquid was not drawn back in the bubble bottles, or in the case of a vacuum apparatus, when the manometer showed no change in pressure on closing the hydrogen supply and exhaust stopcocks.

Since uranium hydride is a pyrophoric and often dangerous material, it is advisable to take the proper precautions when its preparation is necessary.

High pressure work. A steel pressure bomb, about 7 cm across and 25 cm deep, was equipped with a copper-gasketed cover held by bolts, spark plugs for electrical leads to a heating element and thermocouple, and a connection for hydrogen. The heating element was constructed from molybdenum wire wound on a beryllia crucible, which was insulated by concentric nickel cylinders separated by beryllia spacers. The uranium was placed in a pressed uranium nitride crucible inserted in the beryllia crucible. Purified hydrogen was forced in by oil displacement, using a small-bore high-

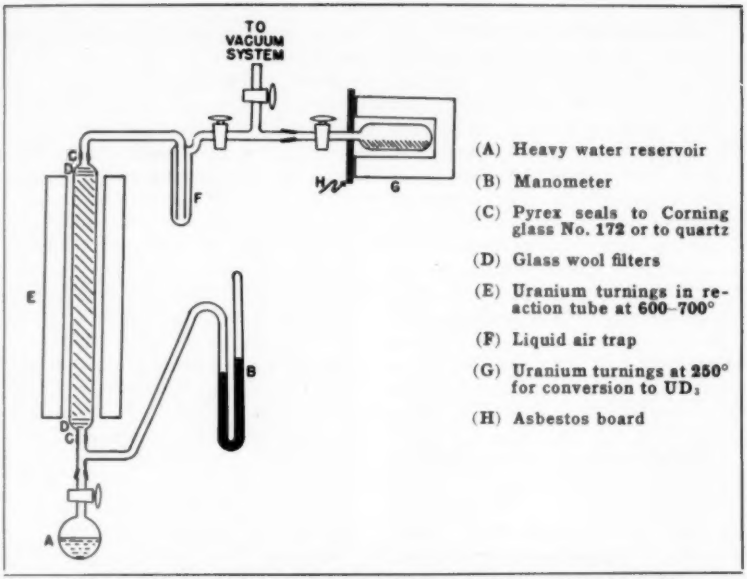

FIG. 4. Apparatus for conversion of heavy water to uranium deuteride

pressure pump. The reaction was usually carried out at 600–700°, and at pressures up to 130 atm.

Conversion of heavy water to deuterium and uranium deuteride. The reaction of steam with uranium turnings at 600–700° being dangerously exothermic, it was necessary to construct the apparatus in such a manner that the reaction was carried out slowly. A convenient set-up for this purpose is shown in Fig. 4. The heavy water in a 50 ml bulb was maintained at about 30°, and was connected to a manometer and reaction tube at 600–700° in a resistance furnace. Reaction tubes were quartz or Corning glass No. 172, charged with uranium turnings. A liquid-air trap served to freeze out any traces of deuterium oxide not reduced, but was unnecessary when the reaction tube contained a large excess of uranium. The deuterium was collected in a flask containing uranium turnings at 250°. In operation, the system was evacuated and the stopcock to the heavy water opened. This allowed the vapors to enter the reaction tube and be reduced to deuterium, which was absorbed by the uranium in the collection flask at 250° to form uranium deuteride. The system thus had an automatic check on the reaction since, if the deuterium was not absorbed in the collection flask (all of the uranium being consumed), the pressure rose and prevented the diffusion of the heavy water vapors. Once the apparatus was started, it was automatic and required no attention, and several grams of heavy water could be converted to uranium deuteride per hour. The deuterium was generated as needed from the uranium deuteride by raising the temperature and/or reducing the pressure.

Density of uranium hydride and deuteride, and U-UH_3 and U-UD_3 mixtures. A helium densitometer similar to that described by Schumb and Rittner (*10*) was constructed. The

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hydride samples were prepared in the specimen bulb directly, using a known mass of uranium, cooled, evacuated; the apparatus was then filled with helium purified over heated uranium powder. The system was periodically evacuated, heated, and a measured volume of hydrogen removed; this permitted calculation of the composition of the $U\text{-}UH_3$ (or $U\text{-}UD_3$) mixture remaining, whose volume was measured. In this way the hydride samples were completely decomposed into uranium metal. The measurements were repeated during re-formation of the hydride. The greatest errors were due to sensitivity of the apparatus to temperature changes, a variation of 0.3° causing a 1% error.

Pressed blocks of uranium hydride. Uranium hydride was packed into a steel die in a "dry box," from which the air had been flushed with carbon dioxide. The powder was compressed up to 22,600 atm by means of a hydraulic press.

Dissociation pressure-temperature-composition studies. Several sets of all-glass apparatus, similar to Abderhalden drying pistols, were constructed, and charged with known amounts of uranium. The samples were heated in mercury vapor to 357°. This temperature could be maintained within 0.2° over long periods of time, barring large atmospheric pressure changes. The tubes holding uranium hydride were connected to manometers and a vacuum system. Hydrogen could be removed from or introduced into the hydride tubes in measured quantities. The time usually required for a $U\text{-}UH_3\text{-}H_2$ system to come to equilibrium was 48 hours, and the criterion for determining whether equilibrium had been attained was constancy of the pressure for a 24-hour period. In some of the work, the bulbs holding the uranium hydride samples were heated by the vapors of boiling sulfur or benzophenone rather than mercury, and in other cases the bulbs were immersed in a low-melting salt bath

Heat of formation of uranium hydride. A calorimeter was constructed from a small Dewar flask containing water, and was equipped with a stirrer and a mercury thermometer reading to ±0.02°. A bulb containing a known quantity of uranium was connected to a vacuum system, and the uranium powdered by conversion to the hydride at 250° and thermal decomposition under vacuum at 400°. The bulb was cooled and immersed in the calorimeter, and purified hydrogen, which was known to react rapidly with the powdered metal at room temperature, was admitted. The temperature rise was noted. The water equivalent of the calorimeter was determined within ±2% by calibration using the heat capacity of a heated copper block.

Reaction rate of hydrogen with uranium at 357°. A bulb maintained at 357° by a bath of mercury vapor and containing uranium (about 10 g) prepared by decomposing the hydride was connected to a manometer, hydrogen supply, and vacuum system. A reservoir of hydrogen at the desired initial pressure was opened to the uranium, and the rate of reaction was observed by measuring the pressure at various time intervals. The reaction undoubtedly caused a local temperature rise on the surface of the reacting metal, but no measurements of or corrections for this effect were made. The same apparatus was used to determine the reaction rate of deuterium.

Separation of hydrogen and deuterium. Mixtures of known composition of heavy and ordinary water were converted to uranium hydride and deuteride using the apparatus shown in Fig. 4. The mixtures were decomposed at 410° and, in the case discussed, 15 minutes were allowed to elapse between sample withdrawals. The gas samples were analyzed using a quartz fiber gas-

density balance, similar to that of Stock and Ritter (*13*). The measurements were made at 0° and the instrument was calibrated with pure hydrogen and deuterium. Errors were ±0.5%.

Discussion

The compounds of the elements with hydrogen are ordinarily considered to comprise three classes: the volatile hydrides, the salt-like or saline hydrides, and the so-called interstitial hydrides. That uranium hydride is a true chemical compound is indicated by the integral value of the hydrogen-uranium ratio, by the X-ray diffraction data, and by the nature of the dissociation pressure-composition isotherms, although the last have some unexplained features. The linearity of the density-composition relationship of uranium-uranium hydride mixtures shows that the system consists of either two phases (U and UH_3) or is a perfect solid solution. The latter possibility is excluded by X-ray data and by the failure of hydrogen to transfer from the hydride to the metal at 325°. This experiment also eliminates the possibility of two hydrides of different dissociation pressures.

The dissimilarity of the hydride crystal structure to that of uranium, and the constancy of the hydride lattice spacing in samples containing uranium metal, proves that the hydride is not a solid solution, and is most likely a compound of definite composition. The extreme state of subdivision of the hydride suggests that it is brittle. Finally, the metallic appearance and electrical conductivity has to be taken into account.

Summary

Together with the methods of preparation and formation of uranium hydride and deuteride, the formula of the compound was discussed and its physical-chemical properties investigated. These included thermal decomposition, physical state, density, electrical conductivity, dissociation pressure-composition isotherms, pressure-temperature relationships, heat of formation, kinetics of formation, and hydrogen-deuterium separation studies. The question of the classification of uranium hydride into one of the customary types of hydrides cannot be considered settled; it does not correspond to any of them in all details and may be either a different type or a border-line case.

* * *

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Performance of 931-A Type Multiplier as a Scintillation Counter*†

Important characteristics of a multiplier tube are the pulse performance under conditions such that individual (or a few) photoelectrons from the cathode contribute to the pulse, and the number and distribution of "dark" pulses. Curves are given for dark current pulse distribution and the effect of temperature, shield potentials and cathode-dynode voltage

THE SCINTILLATION COUNTER‡ represents one of the most important advances in devices for the detection of nuclear radiations since the invention of the Geiger-Müller counter. Although this new detector is still in its infancy, it is for many purposes superior to the older types of detectors, and it holds promise of displacing the Geiger counter for a great many applications. At present the scintillation counter is rather complicated and requires more elaborate circuitry than does the Geiger counter. However, it is already apparent that simplifications can be made along many lines. Probably the end device will be no more involved than present conventional counters.

The principle of the scintillation counter in its simplest form is illustrated in Fig. 1. In this figure, A is a transparent phosphor crystal. When a nuclear particle is absorbed by this crystal, it emits a flash of light. Many crystals have this property. For example, zinc sulfide, calcium tungstate, anthracene, and thalium-activated sodium iodide have been found useful in scintillation counters.§ The flash of light falls on the multiplier B producing photoemission from its photocathode and consequently a current pulse in the output. This pulse is amplified by amplifier C. The output from amplifier C passes through a pulse height discriminator D, which allows only pulses with amplitudes exceeding some preassigned value to be supplied to the count-rate indicator.

The phosphor crystal is chosen for its efficiency in converting nuclear radiation into visible light and for its ability to produce a flash of light of extremely short duration when excited by the nuclear particle. Crystals can be found with flash duration times of 10^{-8} or even 10^{-9} seconds. Since these times are long compared to the processes involved in the multiplier, the resolving time of a scintillation counter can be made to be a small fraction of a microsecond. This is to be compared with the 50 to 100 microseconds resolving time for conventional Geiger counters. This very short resolving time, as compared to many of the older types of detectors, is one of its important advantages.

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† This material was originally published in the December, 1948, issue of *RCA Review*.

‡ M. Blau, B. Dreyfus, *Rev. Sci. Instr.* **16**, 245 (1945); H. Kallman, *Natur und Technik*, July, 1947; J. W. Coltman, F. H. Marshall, *Phys. Rev.* **72**, 528 (1947) and NUCLEONICS **1**, No. 3, 58 (1947).

§ P. R. Bell, *Phys. Rev.* **73**, 1405 (1948); R. J. Moon, *Phys. Rev.* **73**, 1210 (1948); M. Deutsch, *Bull. Am. Phys. Soc.* **23**, No. 7 (1948); R. Hofstadter, *Phys. Rev.* **74**, 100 (1948).

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Furthermore, crystals can be found which can convert the nuclear radiation with several orders of magnitude greater efficiency than is possible with a Geiger counter. This is particularly true in the case of gamma rays for which the efficiency of a Geiger counter is very low. The high efficiency of this scintillation counter is another important advantage of the device.

The pulse height discriminator is necessary because a secondary emission multiplier, even in darkness, exhibits a relatively copious pulse output, and it is necessary to exclude as many as possible of these pulses from the pulse rate indicator. By choosing a suitable phosphor and using the largest practical optical coupling between the phosphor and the photocathode, it is possible to make the pulses due to the scintillation larger than the majority of the dark current pulses.

Obviously, to design a scintillation counter which takes full advantage of the capability of the device, it is necessary to know something about the nature of the dark pulses as well as the pulses produced by the scintillations. The investigation described below was

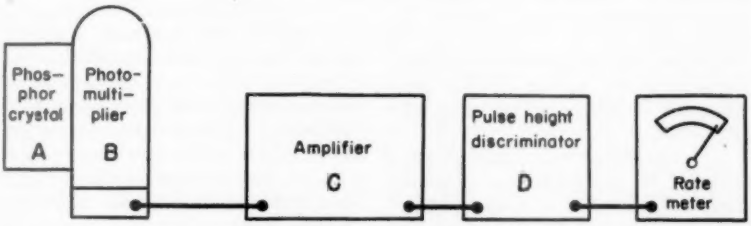

FIG. 1. Schematic diagram of scintillation counter

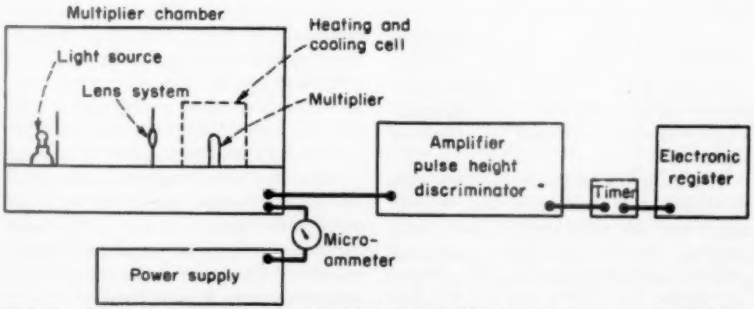

FIG. 2. Experimental arrangement for investigation of pulse performance of multiplier tubes

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undertaken in order to obtain information about the pulse performance of the 931-A and 1P28 type of photomultipliers.

Experimental Equipment

The pulse performance of the multipliers being investigated was measured by means of the amplifier, pulse height selector and register shown in Fig. 2.

The multiplier was contained in a chamber, which was so constructed that it could be operated at room temperature or cooled to dry-ice temperature. A small light source was provided in the chamber so that the multiplier could be tested under various conditions of illumination as well as in darkness. The light source was so arranged that it could be used to illuminate the entire photocathode, or its light could be concentrated into a small spot which could be focused on any point of the photocathode. The circuits in the measuring chamber permitted the measurement of the current flowing to or from the electrodes of the multiplier under test.

The output of the multiplier was supplied to a Bell-Jordan amplifier* through a suitable coupling resistor. The amplifier consisted of a 4-stage preamplifier followed by a 7-stage linear amplifier. The latter was equipped with a pulse height selector which rejected all pulses below any predetermined pulse height. The output of the amplifier was fed to an RCA Decade Timer so modified that it could be used as an electronic register. An electronic timer was used to control the counting time.

The coupling resistor between the multiplier and amplifier was 10,000 ohms and the total capacitance of the coupling circuit, including capacitance of the collector in the multiplier and the grid of the first tube of the preamplifier, was measured as about 30 micromicrofarads. The overall gain of the amplifier used for the multiplier measurements described below was about 10,000.

The amplifier was operated in such a way that the rise time was of the order of 0.15 microseconds and the response time 0.3 to 0.4 microseconds. The scaler would record periodic pulses at a rate somewhat greater than a hundred thousand per second. A determination of the resolving time of the entire system, by means of the self coincidences of random pulses, indicated a resolving time of about 6 microseconds. With this resolving time, pulses from individual electrons leaving the photocathode could be measured on the register.

Experimental

The first phase of the investigation to be discussed concerns itself with the pulses due to dark current in the multiplier. The dark current is, of course, that current which appears at the output when no light falls on the photocathode. This dark current is the sum of several contributing causes. First, and most fundamental, the photocathode emits thermionic electrons which are multiplied by the succeeding dynodes and appear at the collector as part of the dark current. Second, any small amount of residual gas may become ionized giving rise to a current. Finally, cold discharge from points or irregularities on the electrodes and ohmic leakage also contribute to the dark current. The dark current from an exceptional multiplier at room temperature, operating at a voltage of 100 volts per stage, will be of the order of 0.05 microampere or less. It is more usual for a multiplier under these same conditions to have as much as a microampere or more dark current.

If the dark current were entirely due to emission from the photocathode, and

* W. H. Jordan, P. R. Bell, *Rev. Sci. Instr.* **18**, 703 (1947).

each electron released was multiplied by the average gain of the multiplier, the output current would be in the form of pulses, each representing a charge of eG. However, in an actual multiplier, although a stage may have an average gain of R, each electron striking this stage does not produce exactly R secondary electrons. The actual number will be greater or smaller than R with a probability given by some distribution law. Since this occurs at every stage of the multiplier, the pulse height of pulses due to the thermionically emitted electron must also be spread over a distribution. Similarly, pulses due to gas ion effects are not of uniform height but also follow a distribution law. The pulses due to ohmic leakage are very small, and can, without serious error, be neglected in considering a multiplier for use in a counter-type scintillation detector.

Figure 3 gives a typical height distribution curve for a good multiplier at room temperature. The ordinates of this curve are in pulses per second and the abscissa pulse heights in units of the charge, equal to the charge of an electron times the average gain of the multiplier. It will be noted that there are approximately 600 pulses per second with a height equal to one unit of charge eG or greater. If the curve is extrapolated to zero pulse height, the value would be about 1,000 pulses per second (this extrapolation is not valid, due to the fact that it omits the many small pulses due to ohmic leakage currents, etc.). Although considerable quantitative differences were found in the pulse distribution from various multipliers, the curve shown is fairly representative of those found for good multipliers. A less suitable tube used under the same conditions may show 10 to 100 times the number of pulses per second of unit height shown in the figure. It is interesting to note that if one integrates the curve shown in Fig. 3

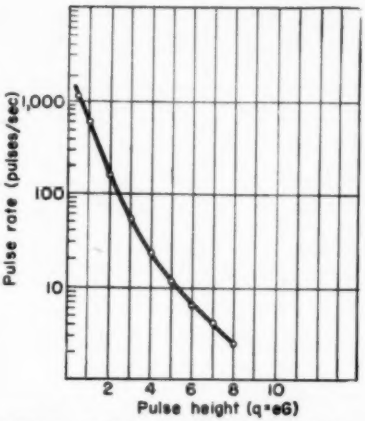

FIG. 3. Typical pulse height distribution curve for a good multiplier at room temperature

to obtain the current represented by these pulses one finds that this portion of the current represents less than 1% of the total dark current. The remainder of the dark current is in the form of very small pulses which are below the amplifier noise level of the system used in the present measurements.

The dark current pulse rate is very dependent on the temperature of the tube. Figure 4 illustrates the variation in number of pulses per second for two tubes over the temperature range from 27° to 50° C. Curve A is for a good tube (type 1P28), curve B is for a considerably poorer tube (type 931-A). It will be noted that the pulse rate changes by a factor of 4 to 10 over this relatively small temperature range. If the tube is cooled to a low temperature, the pulse rate decreases very markedly. For example, the tube shown in curve A, with 500 pulses per second at room temperature, has a pulse rate less than 5 per second at dry ice temperature. In general, the pulse height distribution does not change much with temperature. However, it will be found that the large pulses do not decrease quite

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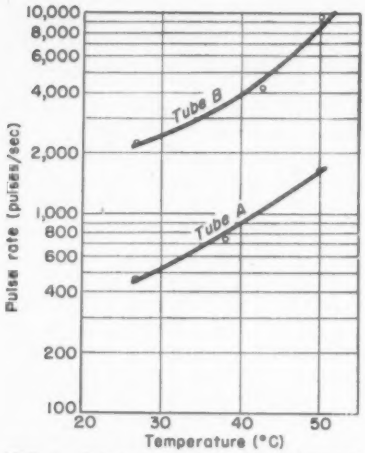

FIG. 4. Illustration of the dependence of dark current pulse rate on the temperature of the tube

as rapidly as the small pulses when the tube is cooled. This effect is emphasized if the shield around the tube is positive with respect to the photocathode (the effect of the electrostatic shield around the tube will be discussed in some detail later).

The number of pulses per second of a given height increases as the overall voltage on the multiplier is increased. This is due to the fact that the gain of the multiplier increases. If the distribution is plotted in terms of a unit equal to ϵG, it is found to remain relatively unchanged with change of voltage over a considerable range, e.g. from 60 volts per stage to 100 volts or more per stage. However, even over this voltage range some change can be noted, as will be discussed later. If the overall voltage exceeds a certain amount, a large number of large pulses appear in the output, the result of cold discharge phenomena in the multiplier.

An external electrostatic shield around the glass envelope of a multiplier may have a marked effect on its noise

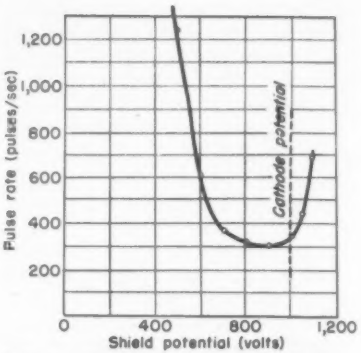

FIG. 5. Performance of a multiplier surrounded by an external electrostatic shield, the potential of which is varied

output.* It is found that a good multiplier having a low pulse output is relatively unaffected by the d-c potential of a shield surrounding the envelope. However, the number of pulses in the output of many multipliers may be greatly changed by varying the potential of the external shield. Figure 5 illustrates the performance of such a multiplier as the shield potential is varied. The collector of this multiplier was grounded and the cathode operated at 1,000 volts. It will be seen that as the shield is made negative to about −800 volts the count rate decreases. In the range from 200 volts positive to 50 or 100 volts negative with respect to the photocathode, the counting rate remains relatively constant. Making the shield more negative again increases the dark current pulse rate. It should be pointed out that while the general effect of shield potential on multiplier performance will be as indicated, there are very large quantitative differences between different multipliers. Although the exact cause of this effect is not known, it is probably due to the

* This effect was first pointed out to the authors by Dr. A. M. Glover, RCA Victor Division, Lancaster, Pennsylvania.

effect of the potential of the inner surface of the glass near the photocathode on ions in the tube. The potential of the inner surface of the glass is altered by the leakage through the glass to the external shield. Where the multiplier envelope is high resistance glass, as in the case of the 1P28, the potential of the external shield makes little difference on the pulse performance.

Performance Under Light Stimulation

The nature of the pulse output from a multiplier stimulated by light is of equal importance with the dark current pulse performance in determining its suitability for scintillation counters. Therefore, a series of multipliers was measured under conditions of light stimulation such that the pulses due to individual photoelectrons could be measured. For these measurements, the multiplier in the measuring chamber was cooled to the temperature of dry ice in order to reduce the dark pulses to a low value. Under these conditions, as has already been pointed out, a good multiplier will produce less than 5 pulses per second of amplitude corresponding to one electron times the average gain of the multiplier.

The effective gain of the multiplier being known, a measurement of the changing output current when the multiplier is illuminated gives a measure of the photocurrent leaving the photocathode. From this photocurrent the number of photoelectrons leaving the cathode each second can be determined directly. Using a known number of photoelectrons per second from the photocathode, the number of output pulses per second as a function of pulse height was measured. Figure 6 illustrates a typical distribution curve obtained in this way. The ordinate of this figure is the number of pulses observed divided by the number of photoelectrons from the photocathodes,

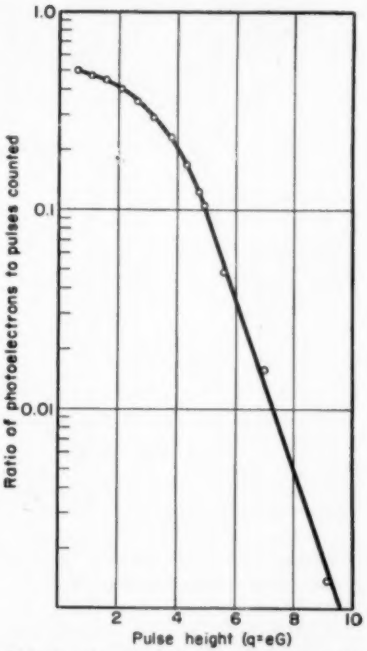

FIG. 6. A typical distribution curve obtained using a known number of photoelectrons per second from the photocathode and measuring the number of output pulses per second as a function of pulse height

while the abscissa, as before, is measured in units equal to the charge on an electron times the effective gain of the multiplier. One of the first things that will be noticed is that the curve does not approach unity for zero pulse height, but rather intersects the axis at 0.7. This means that 30% of the photoelectrons from the photocathode do not reach the output of the multiplier. If the voltage between the photocathode and first dynode is raised, the fraction of photoelectrons which eventually appears in the output is increased. This is illustrated by the family of curves shown in Fig. 7. The distribution curves obtained under the different

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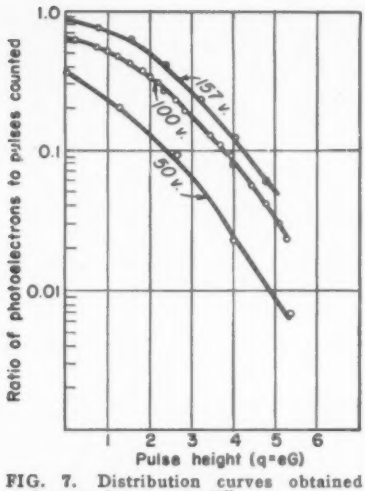

FIG. 7. Distribution curves obtained under conditions of different voltages between the first dynode and the photocathode

conditions of voltage between the first dynode and photocathode are essentially the same. However, when examined in detail, it will be found that the distribution is slightly sharper at higher voltages. In general, the distribution of pulse heights obtained from the light-stimulated multiplier shows noticeably fewer large pulses than it does for the dark current.

The distributions obtained are not those that would be expected under the assumption that the secondary emission from each stage followed a Poisson distribution. Under this assumption, the nature of the distribution curve can be deduced as follows: If the secondary emission ratio for a stage is R, then the probability of Z electrons being emitted when an electron strikes the stage is, by Poisson's Law,

$$P(Z) = \frac{e^{-R}R^Z}{Z!}$$

With this as a basis, a generating function* $F(x)$ can be set up for the n stages in cascade, where

$$F(x) = f_1(f_2(f_3(\cdots (f_n(x)))))$$

and

$$f_k(x) = \sum_{Z=0}^{\infty} P(Z)x^Z$$

$$= \sum_{Z=0}^{\infty} \frac{e^{-R}R^Z}{Z!}\, x^Z = e^{-R}e^{Rx}$$

hence

$$F(x) = e^{-R}e^{Re^{-R}e^{Re^{-R}e^{R \cdots}}}$$

It is a property of this function that the yield expectation is given by

$$\bar{Z} = F'(1)$$

and the second moment by

$$\overline{\Delta Z^2} = F''(1) + F'(1) - [F'(1)]^2$$

Performing the indicated operations, one, of course, obtains the yield expectation

$$Z = R^n$$

and the second moment

$$\overline{\Delta Z^2} = R^n(R^n + R^{n-1} + \cdots R + 1)$$

$$= \frac{R^n(R^{n+1} - 1)}{(R - 1)}$$

If n is a large number, as is the case in practice, the second moment per electron reduces to

$$\frac{\overline{\Delta Z^2}}{\bar{Z}^2} = \frac{R}{R - 1}$$

The actual measured distribution, however, is found to have a second moment of more nearly twice the value predicted by the relation given above. This difference may be because the secondary electrons from each dynode do not follow a Poisson distribution or alternatively, it may be because of the loss of electrons between one stage and the next. The second explanation probably accounts for most of the increase in the spread of the distribution of pulses at the output.

Returning again to the matter of the efficiency of collection of total electrons by the first dynode, a series of measurements was made in which the light was focused on a small spot of the photo-

* T. Jorgensen, Jr., *Am. J. Phys.* **16**, 285 (1948).

cathode. Figure 8 shows a family of curves taken in this way. It is apparent that the photoelectrons from a spot near the inner edge of the photocathode and near the center of the photocathode are totally collected at a relatively low voltage. However, electrons originating from the outer edge of the photocathode require a very high voltage for efficient collection. Again, the pulse height distribution curves obtained from the emitting spot in different positions on the photocathode are almost identical.

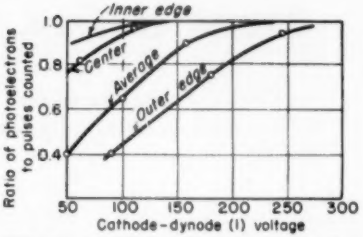

FIG. 8. Curves for efficiency of collection of electrons with a light source focussed on different parts of the photocathode, the cathode-dynode voltage being varied

Conclusion

The curve given in Fig. 3 permits the determination of the number of dark current pulses per second from a good multiplier for any pulse height setting. This, for example, would give the background output of a detector. After selection of the maximum allowable background count for a given application of the scintillation detector, the number of photoelectrons required from each scintillation to ensure its detection can readily be determined with the aid of the curve in Fig. 6. Also from Figs. 7 and 8 it is evident that some improvement in efficiency can be obtained by using a somewhat higher voltage between the photocathode and first dynode. For example, where a multiplier is operated with 100 volts per stage, 150 volts between the photocathode and first dynode ensures a higher percentage utilization of the primary photoelectrons. Finally, a very real advantage can be obtained with some multipliers by operating the tube with a conducting shield around it which is maintained at cathode potential. While the 931-A type of multiplier (i.e., RCA 931-A, 1P21 and 1P28) is by its construction not very well suited for use in scintillation detectors, nevertheless, with proper care a good scintillation detector can be designed around this multiplier.

There is no "atomic secret" that could be purloined by a secret agent and turned over to an enemy of the United States. The real secret of how to produce an atomic bomb or an industrial power plant lies in the "extensive scientific and industrial know-how which our scientists and engineers possess as part of their heritage and education. The real secret is not in how the bomb or power plant operates, but in how to carry out these operations on a large scale so as to make them effective. I think this country is in real danger, from national safety angle alone, of losing its lead in the scientific world due to the emotional approach to the question of secrecy which is so prevalent in certain quarters of our society."

—From a report on a talk by F. H. Spedding, Iowa City, December 3, 1948

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GAMMA RAYS and INTERNAL CONVERSION

Review of experimental and theoretical knowledge of internal conversion, together with data on energy and yield of neutron-capture gamma rays and newly discovered radioactivities

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As EARLY AS 1910, von Baeyer and Hahn (*1*) showed, by use of a magnetic field, that the electrons emitted from a strong, naturally radioactive source consisted of several discrete energy groups superimposed on a continuous electron distribution. The apparatus used by them, together with a copy of their photographic record, is shown in Fig. 1.

After this initial discovery, the importance of the work was recognized and immediate attempts to improve the apparatus were made in order that greater detail might be secured on the photograms. A signal advance was made by Danysz (*2*) in 1912 with the introduction of the semi-circular magnetic focusing spectrometer. Further improvements in the apparatus, made by Rutherford (*3*), Robinson, and Rawlinson, subsequently initiated study of the emission spectra of all the known naturally radioactive substances.

In 1914 Rutherford (*4*) offered an explanation of the observed spectra. While it is now regarded to be incorrect in many respects, nevertheless his theory did suggest for the first time the phenomenon of *internal conversion*. He assumed that electrons were always emitted from the radioactive nuclei with certain discrete energy values. These electrons, on escaping from the atom, transferred, by collision, varying amounts of their energy to the outer orbital electrons. Thus it was that the continuous beta spectrum appeared. Further, the escape of the beta particle, it was assumed, initiated certain natural vibrations in the atom, which caused the emission of characteristic gamma rays. Some of these gamma rays escaped directly, while others interacted with orbital electrons, transferring to them their entire energy. As a result these ejected orbital electrons possessed fixed discrete energies.

By 1921 the phenomenon of nuclear transmutation had been further clarified by the work of Rutherford, Robinson, and others. Two main phenomena usually exist in beta-ray disintegration; namely, the ejection of nuclear electrons, and the nearly simultaneous emission of one or more nuclear gamma rays. The energy of a particular beat particle might be any value in the continuum of values ranging from zero to an experimentally determined maximum. The discrete energy is shared randomly between the electron and an accompanying neutrino. On the other hand, the energy of the gamma ray is always discrete. As a consequence of these primary nuclear radiations, several secondary effects may be induced. The most significant of these is the relatively frequent conversion of the gamma ray in the electronic shell structure of the same atom in which it originated. This conversion results in the subsequent emission of a high speed photoelectron whose kinetic energy is exactly equal to that of the original gamma ray

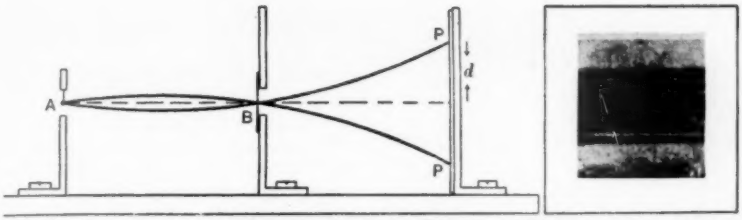

FIG. 1. Reproduction of early apparatus of von Baeyer and Hahn to resolve electron groups; a copy of photographic record is shown on the right

minus the orbital binding energy of the electron.

Since the ejected electron may be a K, L, or an M electron, it follows that from a source consisting of a large number of transmuting nuclei, each of which emits a monoenergetic gamma ray, groups of electrons will be observed whose energies differ by exactly those amounts which have been observed for the well-known K-L-M differences of X-ray spectra. If the gamma ray is emitted subsequent to the ejection of a nuclear beta particle from an element of atomic number Z, then the K-L-M differences must be characteristic of the element $(Z + 1)$, since the loss of a negative charge from the nucleus is equivalent to the gain of a positive charge of equal amount.

An additional secondary effect is the emission of characteristic X-rays due to the refilling of the orbits which were depleted by gamma-ray conversion. This may then be followed by the conversion of the more loosely bound electrons of the outer levels and the subsequent emission of their corresponding X-rays. When it is considered that all of the secondary effects are superimposed on the original gamma-ray emission, which itself may have been multiple, then it is not surprising that the observed radiation is, in certain cases, of great overall complexity.

The probability of internal conversion occurring seems to be much greater in atoms of large atomic number than in the lighter elements. It usually occurs for those gamma rays whose energies lie in the range 50 to 500 kev. As it is usually observed, the conversion probability is greater the more tightly the electron is bound to the nucleus. The ratio of the number of K:L:M electrons converted is, for most gamma rays, usually observed to be about 40:10:1. However, for some gamma rays the number of L electrons converted may be of the same order of magnitude as the number of K electrons converted.

Theoretically, this ratio is of considerable importance since it is intimately related to the spin change, the half-life, and the selection rules characteristic of the nuclear transition. Ultimately these ratios must be determined with considerable accuracy if we are to understand completely the emission processes.

Terminology

At the last International Congress, held in Oslo before the war, the fundamental definitions of certain magnetic units were unanimously agreed upon. The intensity of a magnetic field, denoted by the symbol H, is to be measured in a unit called the oersted. The magnetic induction, which arises when one deals with the force on a conductor in a magnetic field or the EMF induced in a moving conductor, is denoted by the symbol B and is to be measured in a unit known as the gauss.

Most American writers will agree

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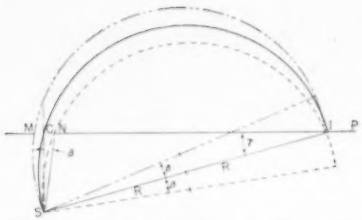

FIG. 2. The magnetic focusing beta spectrometer of Danysz

that the force F on an electric conductor, of length L, carrying a current I, perpendicular to a uniform magnetic field, is $F = BIL$. By the same token, the force exerted on an electric charge e moving perpendicular to a magnetic field (where e is measured in electromagnetic units), should be given by the expression Bev. Equating the centrifugal force of magnetic induction and the centripetal inertial force, it follows that

$$Bev = Mv^2/\rho \qquad (1)$$

or the momentum of the particle, Mv, is proportional to $B\rho$ expressed in gauss-centimeters. Those writers who still insist on using $H\rho$ as a measure of the momentum of the particle, should at least be consistent and use the unit, oersted-centimeter, which they rarely do. From a knowledge of $B\rho$ for a given electron, a value of its energy W may be explicitly obtained since

$$W \text{ (in Mev)} = -M_0C^2 \pm \sqrt{CM_0{}^2C^2 + B^2\rho^2e^2} \qquad (2)$$

where M_0 is the rest mass of the electron and C is the velocity of light.

One property of a charged particle which moves at right angles to a uniform magnetic field is of particular interest: namely, that the time of flight for one revolution is independent of the energy of the particle and of the radius of the path. Since time is distance divided by velocity, we get, by substitution of velocity from Eq. 1,

$$t = \frac{2\pi\rho}{v} = \frac{2\pi\rho M}{Be\rho} = 2\pi \times \frac{M}{e} \times \frac{1}{B} \qquad (3)$$

This shows that the time depends only on the e/M ratio of the particle and the magnetic induction B of the field. This principle, which underlies the action of the cyclotron, is equally important in the functioning of beta spectrometers.

Apparatus

Semi-circular magnetic focusing spectrometer. The first marked advance in the development of beta spectrometers, as previously indicated (*2*), was due to Danysz. The principle of the apparatus is illustrated in Fig. 2. A linear source S, perpendicular to the page, emits beta radiation which is limited by the slit MN. The radioactive source, slits, and photographic plate are arranged in an evacuated box which is placed in a uniform magnetic field perpendicular to the plane of the page. Any electron originating at S and passing through the center of the slit MN will trace out a semi-circular path of diameter $2R$ to the image at point I, lying in the plane of the photographic plate NP.

An electron, in escaping from the source, must penetrate the layer of atoms surrounding it; in doing so, it expends energy, and hence it traverses a path of smaller radius. Thus, for a monoenergetic group of electrons the resulting effect is a widening of the image I.

It is apparent that other electrons passing through the slit adjacent to either M or N make an angle β with the central electron, and meet the photographic plate at a point slightly nearer the source. The width w of the image I for a source S, infinitely narrow, can be seen to be approximately

$$w = 2R(1 - \cos\beta) \sec\gamma \qquad (4)$$

where γ is the angle whose sine is SC divided by $2R$.

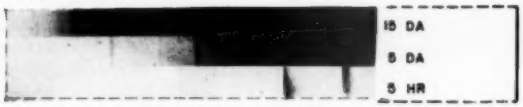

FIG. 3. The conversion spectrum of europium 154, for exposure times of 5 hours, 5 days, and 15 days

In actual practice a slit MN of width about 1 cm is employed, with a distance SC of 4 cm. Consequently, the expected line width at I, for a radius R of 7 cm is about 1.1 mm. However, the line width as observed experimentally might be expected to be greater than this, since the effects of the width of the source at S, and of the mass of material per centimeter of source length have been neglected. It is therefore apparent that the ideal source is an infinitely thin one, but since this would lead to an infinitely long time of exposure, a compromise must be made—that is, a quantity of material which yields photograms in a reasonable length of time, and yet does not produce excessive image broadening, is used. It follows therefore, that the most desirable source is the one possessing the highest specific activity.

The desirability of obtaining exposures of different time duration for each specimen is strikingly shown in Fig. 3. This figure shows photograms of the same source using times of exposure of 5 hours, 5 days, and 15 days. It is apparent that in any single photogram certain lines would have been missed completely either due to underexposure or overexposure.

With the dimensions mentioned above, and no focusing in the vertical plane, it is found that the solid angle subtended by the image at the source is only about 0.15% of the total solid angle and that the resolving power, expressed as the half-width $w/2$ divided by $2R$, is about 0.4%.

The actual line shape in this spectrometer is such that the effective line width is not as great as that calculated above. The theoretical distribution of

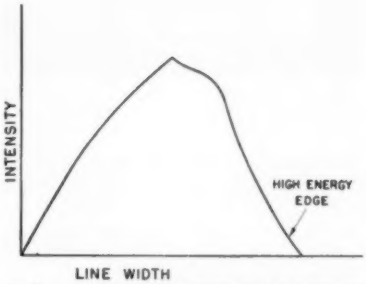

FIG. 4. Electron intensity distribution across the line width

intensity throughout a given line width has been calculated for a cylindrical source and it is found to possess a variation in electron density as shown in Fig. 4. A maximum in intensity exists near the high energy edge as shown at R. As a consequence, the crosshair of the comparator which is used in measuring the photograms is set just within the high-energy edge of the line; thus the line measurement is accurate to a degree greater than expected when the over-all line width is considered.

Since the exposure time may be several days, it is necessary to maintain the magnetic field uniform for long periods of time. While this can be done with automatic current controls, it seems much more desirable to employ spectrometers of the permanent magnet type, such as is shown in Fig. 5. In constructing magnets of this type, Alnico cylinders are arranged symmetrically above the top and below the bottom pole faces. A momentary current through the copper exciting coils gives rise to a uniform remanence in the air gap. In the first few hours after magnetization, the magnetic induction drops slightly but then reaches an equi-

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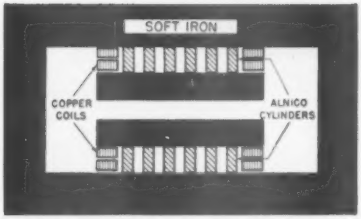

FIG. 5. Permanent magnet as used in photographic semi-circular spectrometers

librium value and remains unchanged for long periods of time. To obtain varied resolving powers, three of the permanent magnet spectrometers are used, being set at about 200, 300 and 400 gauss, respectively.

Electron lens spectrometer. An instrument known as the electron lens spectrometer, shown in Fig. 6, was first suggested by Kapitza and described (*5*) by Tricker in 1924. A source of electrons S is placed on the axis of an evacuated cylindrical cavity as shown, and a uniform magnetic field is set up by a solenoidal winding around the cylindrical wall. It is apparent that any electron emerging from the source S with a velocity V making an angle θ with the axis, may have its velocity resolved into components parallel and perpendicular to the axis. The component $V \cos \theta$ parallel to the axis carries the electron along the axis, while at the same time, the component $V \sin \theta$, acting normal to the magnetic field, causes the electron to trace a circular path of radius R. The combination of both motions results in a corkscrew trajectory which returns the electron to the axis of the cylinder at some distance L swept out by $V \cos \theta$, while in the same time interval the circular path $2\pi R$ is traced by the velocity $V \sin \theta$. Hence it follows that

$$\frac{2\pi R}{V \sin \theta} = \frac{L}{V \cos \theta} \quad \text{or}$$

$$\theta = \tan^{-1} \frac{2\pi R}{L} \quad (5)$$

By placing at the center of the cylinder a lead baffle system of diameter $4R$, shaped as shown in the figure, only those electrons which start from S on a conical surface subtended by the angle θ are allowed to pass. By enlarging the slit width at the baffle, electrons of the same energy, but emerging at an angle θ' slightly greater or smaller than θ, are also allowed to pass. By constructing the trajectories of these electrons it is seen that they meet those electrons emerging at the angle θ at the ring-shaped area I. Thus by placing at I a ring-shaped slit a focusing effect is obtained for a particular energy group of electrons. In practice, the solid angle subtended by the radioactive source is much larger for this instrument than for the semi-circular magnetic focusing spectrometer, allowing the use of much weaker sources. The resolving power, however, leaves much to be desired since it is greatly influenced by the dimensions and placement of the source S as well as by the proper positioning of the slit at I. Just as the momentum Mv was expressed in terms of $B\rho$ for the semi-circular instrument, so it is here given by $B \frac{L}{2\pi \cos \theta}$. For a solid angle of about 0.9% the usual resolving power is about 2%. In practice, it is quite common to use a spectrometer which does not have a uniform solenoidal field but rather, a bunched winding at the center. This results in a true electron lens which may be empirically calibrated to relate the value of the exciting electric current to the energy of the electrons being focused.

Double-focusing spectrometer. It was shown by Eq. 3 that the time of flight of any electron in a uniform magnetic field is the same. Hence it would appear that by properly shaping the magnetic field so that those electrons traversing a longer path had a smaller B, then all of the electrons emerging through a sizable solid angle from a

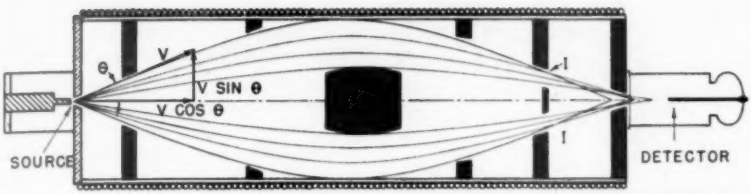

FIG. 6. Arrangement of source and slits in the solenoidal electron lens spectrometer

source S could be brought to a focus at some remote point I. This would appear to be rather simple if the electrons were limited to a single plane, but the problem is considerably more complicated when the electrons may emerge at an angle to this plane. The solution to the problem was first worked out by E. McMillan in considering the functioning of the synchrotron, but it was not published at that time. A brief article on the subject was presented (6) by Siegbahn and Svartholm while a complete solution was carried through (7) by Dennison and Shull, aided by some suggestions from McMillan.

The final result indicates that, if a magnetic field is properly shaped, then it is entirely possible that while the radial vibration δR is taking place, the perpendicular vibration δZ might also be occurring. Thus, at a certain instant the particle arrives back at its original radius and azimuth so that a cluster of electrons emerging from S form an image of the source at this new point I. The form of the magnetic field in the median plane of the spectrometer magnet which has been found suitable is shown in Fig. 7 and is represented by the equation:

$$B = B_0\left[1 - \frac{r-a}{2a} + \frac{(r-a)^2}{8a^2}\right] \quad (6)$$

where B_0 is the magnetic induction at the predetermined constant radius a, and B is the actual field at some radius differing from a by an amount $(r-a)$ or δR. The oscillations in the two perpendicular directions coming together again at an angle $\sqrt{2}\pi$ or 253.8° are shown in Fig. 8. The amazing result is that a line source at S results in an image at I whose central width is almost identical with that of the source. A slight widening occurs at the top and at the bottom of the line. The great advantage of the instrument is that a much larger solid angle of the order of 0.4% may be used, and still yield a resolving power of about 0.33%.

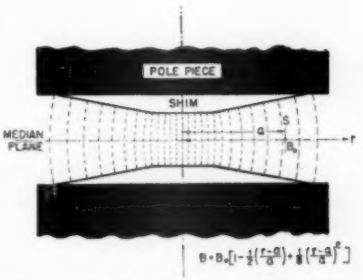

FIG. 7. Section showing magnetic field distribution in the double-focusing spectrometer

Measurement of Magnetic Induction

The classical method of measuring magnetic induction involves the use of a flip coil, consisting of a known number of turns and a known total integrated area, which is connected to a ballistic galvanometer. The galvanometer is calibrated by the use of a standard mutual inductance through which a known current is reversed. This method thus involves an initial and final reading of the galvanometer, as well as an exact

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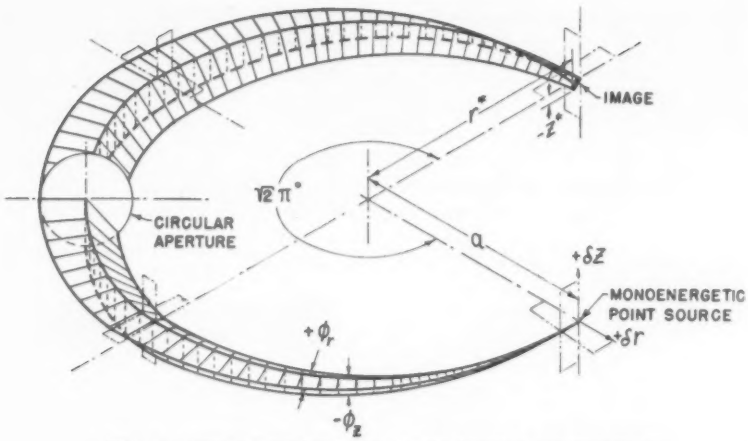

FIG. 8. Image formation in the double-focusing spectrometer

knowledge of the coil dimensions. As a consequence it is futile to expect that the value of B can be determined in this manner with an accuracy $> 1\%$.

In order to expedite the measurements of B, and to improve on the accuracy, a device was developed, as shown in Fig. 9. It consists of a nonmagnetic rotor comprised of copper windings on a slotted, lucite cylinder arranged similar to the windings on an ordinary drum armature of a d-c generator. A commutator of silver segments together with silver brushes is used to lead off the output of the generator with the introduction of a minimum, thermal EMF. The spinner is revolved at a constant rate by a synchronous motor and the output is delivered to a K-2 L&N potentiometer.

The variation in frequency with time of the ordinary commercial power circuit is bound to introduce apparent variations in the output, even though the magnetic field is absolutely constant. A typical variation of a very closely controlled commercial output, where the nominal rate is 60 cycles per second, might be from 59.8 to 60.2, giving corresponding variations in the output. To circumvent this variation in output, a thyratron oscillator was assembled as shown in Fig. 10. This oscillator is driven by a continuously operated Hewlitt-Packard audio oscillator maintained at a constant temperature. With this arrangement the output remains remarkably constant, and because of the high sensitivity of the potentiometer, it is possible to compare two magnetic fields to about one part in 10,000. The absolute measurement of the magnetic induction is, however, much more difficult and uncertain.

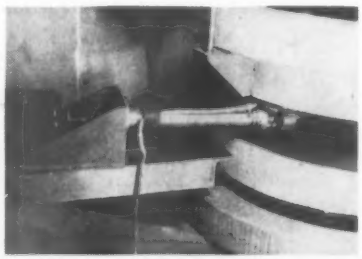

FIG. 9. Photographic view of device for the precise comparison of magnetic fields

To obtain an absolute calibration of the spinner assembly, it is necessary to know some magnetic field precisely. Initially, attempts were made to do this by passing known electric currents through long, parallel conducting bars, then calculating and using the field set up midway between them. However, it was felt that, because of the end effects and the finite dimensions of the spinner, that this field could not be calculated with an accuracy $> 1\%$.

In practice it seemed most expedient to calibrate the generator in terms of the results obtained with the gamma ray from some well-known emitter. Many such gamma rays are known, and one of these is shown photographically in Fig. 11. This figure reveals the K, L, and M electron lines for a gamma ray emitted by a radioactive hafnium (Z = 73) nucleus. It must then follow that the K-L-M differences observed are characteristic of the X-ray levels of tungsten (Z = 74), which are precisely known from X-ray spectroscopy. Because of the high precision with which these energies are known, it is possible to infer the absolute value of the magnetic induction to about one part in 300.

Results

The many specimens examined in this extended investigation have been obtained by neutron bombardment, through the Atomic Energy Commission, either at the Oak Ridge pile or at the Argonne National Laboratory. The nuclear reaction leading to the formation of the radioactive isotope is, in most cases, that of neutron capture. In a few instances, the radioactive emitter is found to be simply the excited state of the stable isotope. In the former case, beta emission usually occurs accompanied by one or more almost simultaneous gamma rays; in the latter case, only the gamma radiation is observed. The clue to this reaction is the value observed for the K-L difference.

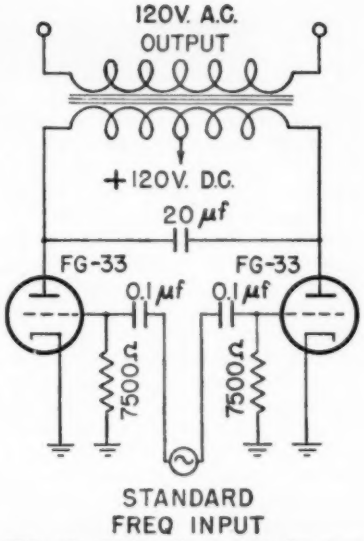

FIG. 10. Wiring diagram of thyratron oscillator to yield a constant frequency (60 cycles/sec) output

If the beta ray precedes the gamma emission then the K-L difference will be characteristic of the element, higher by one, in the periodic table. Another reaction that sometimes occurs in the pile, is the emission of a proton following the entrance of the neutron. This leads to an isotope of the element Z-1, where Z is the atomic number of the element bombarded.

For some of the radioactive isotopes studied it was apparent that gamma rays were present although not internally converted. Where possible, the

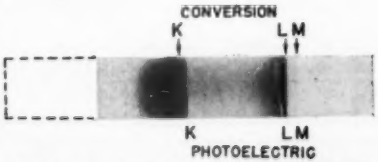

FIG. 11. Low-energy part of electron spectrum from radioactive hafnium

FIG. 12. Electron spectrum obtained from a source of activated ytterbium

energy of this radiation was determined by noting its absorption in some element such as copper or lead. In the main, however, it has been the object of this investigation to discover the electron lines due to the conversion of gamma rays, and then to interpret these lines so that the energy of the parent gamma rays might be evaluated. The half-lives of the various emitters under study have also been determined over long periods of time. As a result of the long and powerful bombardments given the specimens in the pile, many previously unknown radioactivities have been discovered, and the yield of converted gamma rays in the heavy elements has been beyond expectation.

An illustration of the prolific yield in certain elements is presented in Fig. 12. This is a copy of a photographic plate exposed to a source of radioactive ytterbium. In total, over thirty electron lines were measurable on the plates from the element. Iridium, tantalum, and europium have proved to be equally rich in their yields of electron lines.

To determine the gamma energies responsible for the electron lines, it is first necessary to construct a plot of the energy of each electron line as shown in Fig. 13. This represents the energy spectrum observed for the element tantalum. Now by sliding along this plot a scale, on which has been marked the K, L, and M energies characteristic of tungsten $(Z + 1)$, it is possible to pick out those combinations of two or three lines which are due to a single gamma ray. The results obtained with the many isotopes studied are shown (*8*) collectively in the table. These are of course not all of the possible isotopes, since many have still to be investigated. The isotope responsible for the radioactivity observed as listed in column 4 is, in some cases, not known with certainty.

Having evaluated the gamma rays characteristic of a single isotope, it is possible in some cases to construct an energy level scheme for that nucleus. From the numerical combinations and identities observed, these proposed plans cannot be far from the truth. Figure 14 shows a suggested level scheme for the nuclear levels in tantalum as derived from the observed gamma rays. It seems likely that all of the heavy rare-earth elements will be equally interesting when available.

Some Observations from the Results

Quantitative analysis. Since the cross section for neutron capture is extraordinarily large in certain isotopes, it is at once apparent that this method might lead to the detection of impurities when they are present in very minute amounts. For example, if the cross

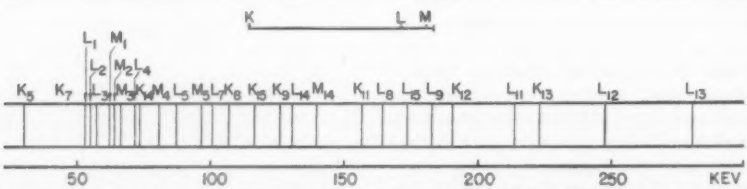

FIG. 13. The electron lines observed from radioactive tantalum, (Z = 73) with accompanying scale showing K-L-M separation in tungsten (Z = 74)

Summary of Results on the Elements Studied

Element				Gamma Energies	
Z	Name	Half-life	Probable Isotope	By Absorption	By Internal Conversion
21	Scandium	76 d	46	1.15 Mev	No lines
23	Vanadium	174 d	52		80.0, 119.2 kev
47	Silver	282 d	110	1.38	114.2, 655, 880
48	Cadmium	64 h	115	0.61	86.3, 336.9
		75 d	107 or 115		
49	Iridium	48 d	114	0.81	190.9
52	Tellurium	30 d, >2 y	122 or 126	0.83	87.0, 108.2, 157.2
53	Iodine	13 d	126		78.8, 147.9, 165.0, 284.8, 365.0
55	Cesium	2 y	134		598.2, 790.0
57	Lanthanum	43.4 h	140	1.60	
		~3 y	140	0.79	
58	Cerium	—	141 or 143		137.1, 143.9
59	Praseodymium	19.2 h	142		133.7, 328.9, 489.6, 624
60	Neodymium	50 h	147		
		11.8 d	147	0.72	
		~1.7 y	147		
62	Samarium	50 h	153		102.1
		>150 d	155	0.95	242.4
63	Europium	~6 y	152, 154	1.23	39.9, 122.1, 247.3, 286.0, 342.8, 407.8
65	Terbium	77.3 d	160	1.15	85.6, 194.8, 212.1, 296.5
68	Erbium	~42 h	169 or		81.9, 125.7
		>100 d	171		113.0, 119.5, 130.4, 153.4, 138.2, 176.8, 197.8
70	Ytterbium	~40 h	175 or 177		84.1, 95.8, 96.9, 109.3, 137.8, 206.0
		>100 d			84.5, 88.9, 113.1, 259.3
72	Hafnium	55 d	181		132.4, 344.2, 378.0
73	Tantalum	97 d	182	1.2	64.8, 66.7, 69.2, 83.6, 99.6, 101.1, 112.5, 142.9, 176.2, 185.6, 195.1, 218.3, 218.3, 225.0, 259.0, 292.0
75	Rhenium	16 h	188		153.5
		91 h	186	0.64	122.7, 135.8, 137.5
76	Osmium	17 d.	192		129.1
77	Iridium	60 d	194		269.0, 293.7, 306.2, 314.8, 401.4, 408, 465.5, 476.8, 586.2, 601.4, 601.4, 610.0, 651.4
79	Gold	2.7 d	198	2.5	408.0
83	Bismuth	5.0 d	209 (Pb)		105.2

section for neutron capture in element *A* is 1,000 barns and in element *B* only 0.1 barn, then even though the concentration of element *A* in element *B* is only one one-hundredth of one percent, its spectrum might appear equally strong. An example of this sort is illustrated in Fig. 15 in which iridium is present in such minute amounts in osmium that it could not be revealed by the ordinary methods of spectroscopic quantitative analysis. Its presence, however, was revealed very positively in the electron spectrum. This use of the pile in

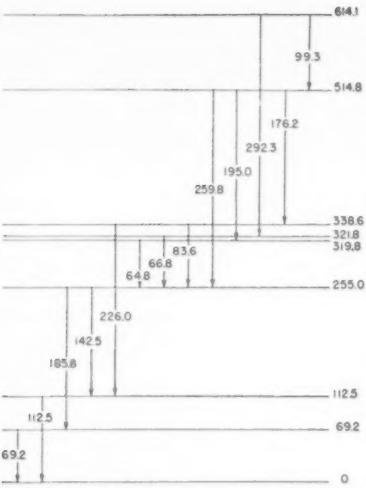

FIG. 14. Energy level scheme for the tungsten nucleus after beta emission from tantalum-182

quantitative chemistry may have considerable importance in certain special cases and adds another to the list of its peacetime applications.

Photoelectric effect and internal conversion. In a few instances electron lines have been observed which seemed to be due in part to ordinary internal conversion and in part to the photoelectric absorption of the same gamma ray in other atoms of the radioactive material. When this double phenomenon occurs for a certain gamma ray, two K lines are observed which differ in energy by an amount equal to the characteristic difference of the K levels for the two adjacent elements. The L differences are very small, and the M lines for the two processes are almost identical. An example of this sort is shown in Fig. 11. A gamma ray from hafnium, on internal conversion, shows the K-L-M differences characteristic of tantalum. By photoelectric absorption in the hafnium atoms, the K-L-M differences characteristic of this element also appear. The ratio of these two effects should be altered by changing the thickness of the source. On doubling the source, the number of conversion electrons should be twice as large but the number of photoelectrons should be four times as great since both the number of gamma rays and the number of scattering atoms are doubled. A similar result has been noted in europium and some other elements. A notion of the resolving power in the photographic spectrometer may be gained by noting that the two K lines shown in Fig. 11 differ in energy by only 2 kev.

* * *

This extensive investigation has been made possible by the continuous and generous support of the Office of Naval Research and the Atomic Energy Commission. This work could have been carried through only with the very fine cooperation of the entire staff on this project, among whom are Mr. R. G. Shreffler, Mr. C. M. Fowler, Dr. F. B. Shull, Mr. H. B. Keller, Mr. E. Salmi, Mr. A. E. Stoddard, Mr. W. C. Rutledge, and Mr. J. Sazyinski.

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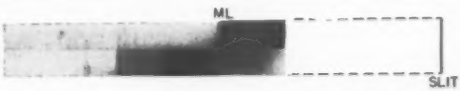
FIG. 15. Photogram showing the presence of iridium in osmium sample



IRE and AIEE Hold Instrumentation Conference

MORE THAN 800 PEOPLE attended the "Conference on Electronic Instrumentation in Nucleonics and Medicine," held in New York last month, and jointly sponsored by the Institute of Radio Engineers and the American Institute of Electrical Engineers. Twenty-six papers were presented during the three-day meeting, with the eighteen given on the last two days being devoted to the nucleonics field.

The following reports on the nucleonics instrumentation papers were written by E. E. Goodale, General Electric Company, Schenectady, N. Y.; Frank Rockett, associate editor, Electronics; and C. Sheer, Columbia University.

* * *

Biological Requirements for Radioactive Isotope Measurements, by C. A. Tobias, Jr., *University of California, Berkeley, Calif.* *Discussion by* L. Marinelli, *Argonne National Laboratory, Chicago, Ill.* There are now a great many kinds of biological research being carried on with equipment which is suitable. However, the field is large, the research is only in its beginning phases, and there are many problems yet to be solved.

Tabulated below is a summary of the present status of measuring techniques.

In an actual experiment, the first difficulty arises with the receipt of the isotope. Before it can be used the absolute rate of disintegration must be determined. With present methods measurements of this kind on a single sample have been found to differ by 600%. Work is being done at the Bureau of Standards to improve this situation, and some of the workers have built their own equipment (special air-filled ionization chambers) for the job. If, however, a reliable model of such a device were available commercially, it would be a boon to the biological worker.

Samples	β	γ	α
In vitro (biological samples)	X	—	X
In vivo (in living bodies)	—	—	O
Radioautographs	— not suitable		X

X = extensive application
— = not good enough instruments available
O = not done very often

The second difficulty is with the number of samples required to do a thorough job. For example it may be desirable to take tissue samples from 20 different places on 10 different animals at 10 different times, a total of 2,000 samples! Then if the samples are α or soft β emitters special methods must be used to prepare the samples so that self-absorption is minimized. The trouble then is the length of time required for processing and measurement of the large number of samples. Good equipment for the biologist should have the following characteristics:

- **A.** Counter—should be highly efficient
- **B.** Amplifying and recording equipment
  1. Should be fully automatic
  2. Should have decade scaler
  3. Should incorporate automatic sample changer for perhaps 1,000 samples
  4. Should incorporate automatic recording

To date, counter efficiencies of 70% have been achieved (for β's). As to

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the other qualifications, so far they have been only partially fulfilled.

With gamma-emitting isotopes special problems arise due to the low efficiency (0.2–0.4%) of presently available counters. This means that, for experiments with humans, injections so large as to be dangerous are required to get measurable counting rates. However, it is felt that with the development of the scintillation counter this difficulty may be overcome. With good phosphors, and proper circuitry, efficiencies of 20% have been obtained with this type of counter, about 150 times that of a Geiger-Müller tube of similar volume. Several laboratories are presently designing such counters for biological work, and it is hoped that they will be suitable for gamma-ray studies *in vivo*.

The directional characteristics of the counter arrangements are also important. One of the chief problems is the location of the exact source of radiation, so that counters with better directional sensitivity would be very helpful.

The use of counting-rate meters for time studies is not too satisfactory because of the fact that a counting-rate meter must either have considerable time lag or show objectionable fluctuations. More satisfactory would be an automatic recorder which would record the counts per unit interval. Such a recorder is not at present available commercially.

With alpha emitters and the radioautograph technique it is possible to determine something of isotope distributions within the cells. The biologists would also like to use this technique with beta-emitting isotopes, but have not yet overcome the difficulties due to the finite range and the scattering of the beta particles.

Discussion: Whereas the electronic circuits meet most of the requirements, this is not true of the available detectors. Since only minute amounts of radioactive isotopes can be safely allowed in living tissue, high sensitivity in the detecting elements is very important.

Since the background count is the limiting factor for any counter, what is desired is maximum sensitivity with low background. This is particularly true for measurement of samples *in vivo* (living animals). Here high sensitivity must be stressed because the solid angle intercepted is necessarily small. The directional response is also of great importance, since it is desirable to locate accurately the source of the radiation.

For measurement of liquid samples containing gamma emitters some special chambers can be used. A G-M tube can be mounted in a somewhat modified 250 cc beaker, so that the liquid sample can be poured around the tube.

For more sensitive measurements an ion chamber (a so-called "pulse chamber," which functions as a counter, but has no gas amplification) was developed in which one electrode contained the liquid sample. This had somewhat more sensitivity than the first arrangement.

Due to the finite travel of beta particles, measurement of the beta activity of a liquid sample is difficult, and to date satisfactory chambers or counters have not been developed.

Gas samples can be measured if the gas can be inserted in the counter, with the precaution that the walls must be decontaminable.

* * *

Geiger Counters, by H. Friedman, *Naval Research Laboratory, Washington, D. C.* Essentially the Geiger counter is a discharge tube usually containing a fine wire anode and cylindrical cathode coaxially mounted. A common design would have a cathode cylinder 1 cm in radius and about 15 cm long, and an anode wire of perhaps 0.0001 cm radius. Such a tube is normally operated at

a voltage between 1,000 and 2,000 volts with a radial field between the electrodes.

For hydrogen gas at 10 cm pressure the field strength would vary from about 2 volts per mean free path near the cathode, to about 20 volts per mean free path near the wire. The latter is equivalent to 50 kilovolts per cm so that ionization can occur at a distance of 4 mean paths from the anode wire. Consequently the generation of primary ionization by the passage of an ionizing particle or ray starts a cumulative avalanche of ionization lasting from 10^{-9} to 10^{-8} sec.

Excitation of the gas atoms during this avalanche results in the emission of photons, usually in the ultraviolet region, which, if sufficiently numerous, will cause the discharge to spread by the production of new photoelectrons from the gas or cathode cylinder. The discharge spreads along the tube by this mechanism at a velocity of about 10^5 to 10^6 cm per sec, depending on the voltage and the pressure. The discharge is, at first, confined mainly to the region of high potential gradient near the anode wire, surrounding the latter with a sheath of positive ions and effectively shielding it, thus forming a virtual anode of larger radius than the wire itself. The net effect is to lower the potential gradient in the main body of the counter to the point where further cumulative ionization is no longer possible. Hence the discharge stops when the sheath extends along the entire anode, the free electrons are swept almost immediately to the anode and the positive sheath begins to expand toward the cathode under the impetus of the field. This causes the pulse to grow in the external circuit as the positive ions are neutralized at the cathode, reaching a peak in the order of 1 or 2 microseconds. The output pulse, developed across an external resistor, will then decay exponentially at a rate determined by the time constant of the circuit.

During the growth of the pulse and until a sufficient number of positive ions have been neutralized to raise the potential gradient above the threshold value for cumulative ionization, the counter is completely insensitive to another particle. This corresponds to the deadtime which may be of the order of 10 to 100 microseconds depending on a variety of conditions. Following this is the recovery period when the counter responds to another event but delivers a smaller pulse than when in the completely recovered state. This lasts from the time the voltage gradient has exceeded the threshold value until it reaches once more its initial value; it depends on the time constant of the circuit. The recovery period may last from 10 or 20 microseconds to several hundred microseconds and is obviously important in setting the upper limit to the counting rate.

In the simple gas counter, described above, spurious pulses may be rekindled during the recovery period and after it. This results from the fact that many of the neutralized positive ions may remain in an excited metastable state, since the ionization energy is usually considerably greater than the energy required for neutralization (work function of the cathode). Moreover these metastable states may last as long as 10^{-4} sec following which photons are emitted in the ultraviolet region; this can ignite another discharge by photoelectric emission. In order to quench such spurious discharges certain polyatomic gases, which absorb strongly in the ultraviolet, may be added to the counter. Counters containing such gases, usually alcohol or other organic vapors, are called self-quenching counters and have a lifetime limited by the quantity of the quenching gas, since the molecules of these vapors are decomposed by the ultra-

violet absorption. About 10^{20} molecules of a quench gas are introduced in an ordinary counter of this type and about 10^{10} are decomposed by each count. This gives a maximum life of 10^{10} counts with a figure of 10^9 counts actually achieved in practice.

The threshold voltage may be reduced considerably, likewise by the introduction of gaseous impurities. For example, traces of hydrogen or mercury vapor added to neon or argon counters, or organic vapors like ethyl acetate added to neon-argon mixtures, have reduced threshold voltages from the order of 1,500 volts to a few hundred volts. A particular counter containing 50 cm of neon-argon mixture with 1 mm of ethyl acetate yielded a threshold of 350 volts and a plateau 150 volts wide. A lifetime of only 10^7 counts was achieved, however. The halogen vapors, to the extent of about 0.5 mm, added to the rare gases provide a non-decomposable self-quenching counter having low threshold voltage and theoretically unlimited life. The difficulty with these gases is to provide electrodes that will successfully resist corrosion by the halogens during prolonged operation.

Structurally Geiger counters have been fabricated in almost innumerable varieties for special purposes. They vary in size from the miniature tubes 3 mm long by 0.8 mm in diameter (fabricated by the Bureau of Standards and used in medical work) to the two-foot-long cosmic-ray counters. The main departure from the more common design described above results from an effort to obtain increased efficiency in the measurement of X- and γ-radiation. In the case of soft X-rays the absorption in the gas itself is sufficient for good efficiency even at pressures as low as 10 cm. Efficiencies between 50% and 100% are obtained for these counters. The problem is the design of a sufficiently thin window to admit the X-rays. A thin metal window of low atomic number such as beryllium or a very thin bubble blown into the end of a glass walled counter have been used successfully. Glass bubbles transmitting as low as 1,000-ev X-rays have been made.

In the case of hard X-rays and γ-rays the situation is considerably more difficult. The absorption of γ-rays is so low that ordinary counters may have efficiencies as low as 1% for 1 Mev γ-rays. The bundling of a large number of cylinders operating in parallel has been used to increase the efficiency. The improvement over a single counter is roughly in the ratio of the number of counters in the bundle to the number along a diameter of the bundle. Another design consists of stacking a number of parallel disks having numerous holes situated directly above each other for each disk, with anode wires running centrally through each. The increased surface area results in something like a ten-fold improvement in efficiency over a single counter. A ten-disk counter with the disks separated by 2 mm can yield efficiencies between 20 and 30%. A structure, also having stacked disks but with the anode wires running radially from a central anode support, gave an efficiency of 8% for γ-rays. In the use of multi-element arrangements for γ-rays, counting the background may be improved by eliminating coincidence counts, since cosmic-ray background will fire all elements whereas the γ-ray usually fires but one. A differential counter, having an efficiency which is a function of direction, may be built by suitable choice of metal and arrangement of the electrodes. This is useful in locating the direction of incident radiation.

* * *

Thin Window Beta Counters, by F. C. Henriques, *Tracerlab, Inc., Boston, Mass.* Most β-ray sources emit par-

ticles of energies too low to penetrate the walls of a standard G-M counter, and all β-emitters show a continuous spectrum of β-particles. Thus, even though the maximum energy may be high enough, the low-energy portion of any β-ray spectrum will be lost by absorption in the walls of ordinary counters. Thin-window counters have been developed to extend the range of measurement to as low an energy as possible with the limit depending obviously on the thickness of the window.

The construction of a thin-window counter differs from that of an ordinary counter by the presence of the thin window at one end of the cylinder. The window usually consists of mica, although nylon or collodion membranes have also been used. The window is cemented to a flange, the surface area of which depends on the pressure differential against which the window is operating. This must be fairly large when the counter is operating against nearly atmospheric pressure. The seal may be made by ordinary vacuum-tight waxes or cements although better results are obtained by a vitreous mica-glass seal. The cathode cylinder, which may be the body of the counter itself or a cylinder of metal on the inner surface of a glass tube, may be composed of a variety of materials, such as copper, chrome-iron, silver, carbon, etc. The central wire is attached only at one end of this type of counter, having a free end very close to the window. A glass bead is usually fused to the free end to minimize disturbing field effects due to the wire discontinuity.

Window thicknesses, measured in milligrams per sq cm, depend on the lower limit required for a particular application. The β-rays from Ca^{45} and Co^{60} can be measured adequately with counter windows of 2 to 3 mg per sq cm. Those from C^{14} and S^{35}, with energies of the order of 0.15 to 0.17 Mev and of particular interest to the biologist, require a window of 1 mg per sq cm or less. On the other hand it is practically impossible to make a window that will transmit the β-rays from tritium.

The self-absorption of β-rays by the emitting substance itself is a serious problem in reducing intensity. The technique of preparing samples for measurement involves spreading the material over as thin a surface layer as possible.

Counters with extremely thin-windows are usually filled to a pressure very near atmospheric. A pressure only 5 cm less than atmospheric is often used, the counter being filled with helium to obtain voltage thresholds of reasonable value. In special applications, such as β-ray spectroscopy, the pressure may be much lower within the counter, since the space outside the counter is evacuated. For measurement of H^3 and the extreme low energy region of β-spectra (less than 25 kev), a windowless counter has been devised in which the sample is placed within the tube itself. This device is inconvenient to the extent that a pumping system is a required auxiliary and the counter can be easily contaminated. It is, however, about twice as effective with, say, C^{14} than a regular thin-window counter.

One of the difficulties with thin-window counters is the accumulation of charge on the window itself. This disturbs the field distribution sufficiently to shift the counter threshold since the counter operation is quite sensitive to the field distribution in this part of the counter. A sort of hysteresis effect is thus produced reducing the reliability of the counter. This effect may be reduced by a thin conductive coating on the inside of the window. This would be at the expense of plateau length which is also reduced by this procedure. However, a suitable choice

in quenching gas may lengthen the plateau to a useful size, resulting in an over-all improvement in the reliability of operation.

* * *

Autoradiographic Techniques, by G. A. Boyd, *University of Rochester, Rochester, N. Y.* Basically the autoradiographic technique is a method of tracing the deposition of a radioactive substance by means of a photographic record of its distribution. The method has been applied successfully to anatomical, cytological, histological, chemical and physical problems. The applications cited here are mainly histological and cytological.

Thus far, the radioactive substances used have been mainly α-emitters since these particles have the most pronounced effects on the photographic emulsions. However, considerable effort is in progress on the development of a technique that would work well with β-rays, thus expanding the method to include the much larger number of β-emitting substances.

A classification of techniques is as follows:

1. The specimen (containing the radioactive element) is placed on the emulsion temporarily, being removed prior to development. This method is useful for gross anatomical, low-magnification histological chromatographic, and chemical applications.

2. The emulsion is painted on the specimen where it remains permanently. This method is most suitable to high-magnification histological and cytological studies.

3. The specimen is placed on the emulsion permanently.

4. A special emulsion is attached to the specimen by means of a layer of cellulose ester from which it is stripped after exposure.

The latter two methods have advantages in specialized applications.

The first technique has produced good results in showing the distribution of radioactive materials deposited in bones, hair follicles, and similar structures. The second method is used to show the uptake of radioactive iodine in thyroid tissue. The third method was demonstrated by autoradiographs of human thyroid tumors, showing again the presence of I^{131}, as well as the uptake of polonium in rat livers. The latter demonstrated the characteristic star or "sunburst" pattern of the α-emitters. Special X-ray plates, more sensitive to β-rays, were employed to show the distribution of C^{14} in lymphocytes, erythrocytes and polymorphonuclear leucocytes, similarly exposed by this method. The stripping technique was exemplified by a photograph showing sunburst patterns from blood plasma.

The minimum dose of I^{131} necessary for autoradiography of a rat thyroid is one microcurie of I^{131} per kilogram of rat, the biopsy being performed 24 hours after injection and placed on an NTB emulsion 6 microns in thickness and exposed for 24 hours. A tissue slice 7 microns thick was used, fixed in formalin and alcohol, and transferred to the emulsion within 3 hours of the biopsy.

Certain interesting chemical applications were described. An autoradiograph of a dilute ionic solution of polonium, suddenly frozen, showed a colloidal type of aggregation. Also shown was a β-track from C^{14} in a filter paper chromatographic spot for the determination of amino acids. In this case the contact was made between the filter paper and the emulsion by a drop of water which sealed them together upon drying.

In general, the NTP plates were found to be best for microscopic work. The requirements for autoradiographic emulsions are: small grain size, low fogging, high speed, and high sensitivity.

Stable Isotope Measurement, by David Rittenberg, *College of Physicians and Surgeons, Columbia University, New York, N. Y.* The measurement of stable isotopes reduces essentially to the problem of the design of a mass spectrometer. There are two types of mass spectrometers, from the standpoint of function:

1. An instrument capable of measuring the absolute mass of an isotope with high precision

2. An instrument which measures the relative abundance of two or more isotopic masses but with less absolute precision

The principle of the mass spectrometer is analogous to that of an optical spectrometer, wherein crossed magnetic and electric fields take the place of a dispersive medium, and the paths of the ions are analogous to the rays of light. In the mass spectrometer isotopes to be separated are ionized in an ion source and accelerated through a fine slit from which they diverge into the focusing field. An elementary calculation will show that the point at which these ions are focused in an "image plane" is dependent upon the ratio e/m for the ions, or, assuming only singly ionized particles, upon the mass alone. Consequently, a slit placed in the image plane and moved laterally will admit ions of different mass into a detection chamber designed to read the ion current. The presence of a particular isotope will therefore be registered as a peak in the curve of detector current versus lateral position of the slit. In operation, however, it is more convenient to keep the detector slit constant and vary the magnetic field, thus accomplishing the same purpose. Obviously, the height of the peaks will be proportional to the relative abundance of the particular isotope corresponding to that peak in the source material used.

The radius of curvature of a charged particle in crossed electric and magnetic fields with magnitudes V and H, respectively, is given by

$$r^2 = 2mV/eH^2$$

If V equals 600 volts, H equals 2,000 gauss and m is of the order of 30, then r comes out between 10 and 15 cm. The resolution of a mass spectrometer is thus dependent on the radius of curvature, and an upper limit to the resolution may be set by the physical size of the instrument. Resolution is also determined by the slit widths as in the case of the optical spectrometer. The requirements of a good practical instrument may be listed as follows:

1. As high a maximum resolution as possible. For biological work a resolution of at least 50 is required.

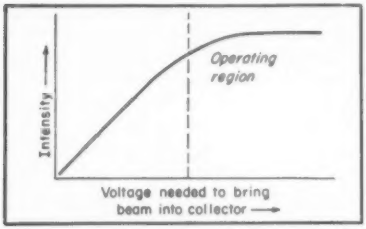
2. The accuracy in the measurement of relative intensities of a satellite to a large peak should be of the order of 0.5%.

3. Simplicity—a minimum of adjustments is highly desirable in practical operation.

4. An ion source yielding as high an ion current as possible. The difficulties encountered in a practical apparatus are inversely proportional to the ion intensity.

Constructionally, most mass spectrometers may be divided into two types: the sector type and the 180-degree type. In the sector type, one has the advantage of requiring a small magnet, the fields being of the order of 2,000 gauss. This type is also capable of yielding high absolute precision and can be made entirely of metal. It has the disadvantages, however, of being very difficult to align and providing a low ion current. To obviate this a very high intensity beam is necessary in the ion source, which brings up the background. Also, an auxiliary focusing magnet is necessary, which is often very difficult to adjust, due to interaction of this field with the main focusing field.

If a plot is made of the ion current intensity versus the voltage needed to bring the beam into the collector, one obtains the characteristic as follows:



The sloping portion of this curve is a very poor region on which to operate, in view of the difficulties of maintaining adjustments. In the sector instrument, the flat region which is obviously the desirable operating region, may require voltages too high for practical use.

The 180° instrument requires a very large magnet in order to obtain a good radius of curvature. For example, the magnet and coils of a particular instrument, giving a radius of curvature of 10 cm, weigh approximately 750 pounds, whereas, for a 60° sector instrument yielding a radius of curvature of 15 cm, the weight is only 150 pounds. However, the former has the advantage of being easy to align, requiring no auxiliary magnet and having no appreciable voltage effect, since the emission of ions takes place in the magnetic field. It also is capable thereby of yielding a much larger ion current.

The associated electronic equipment for a mass spectrometer is quite standard, although the problem of a highly stable amplifier still remains a serious one. The statement was emphatically made that an improved ion generator would considerably mitigate the amplifier problem. Also, an automatic electronic circuit which would keep the instrument adjusted on the top of a peak was called for. A summary of desirable criteria for the design of an ideal spectrometer was given as follows:

1. The ratio of peak to valley should be of the order of 10,000.

2. The peak which is present as background should disappear as the gas is pumped out of the instrument, so that the ratio of the peak at atmospheric pressure to the peak at ⅓ of an atmosphere is over 300.

3. The ion gun should be so designed as to give a high gradient with a low total accelerating voltage, so as to flatten the accelerator potential versus ion intensity characteristic.

* * *

Biological Effects of Radiation and Health Protection, by G. Failla, *College of Physicians and Surgeons, Columbia University, New York, N. Y.* Any cell can be damaged, or killed, by radiation. The dose required depends on the so-called "radiosensitivity" of the cell or organism. Not only is the radiosensitivity different for different types of cells, but it varies widely in different specimens of the same type of cell, or organism. A typical "survival curve" was shown where percentage survival (in this case, of fruit fly eggs) was plotted against total radiation dose. This curve indicated that, whereas about 50 roentgens would kill a small fraction of the specimens, nearly 450 roentgens were required to kill all of them. For other animals the survival curves were similar. However, it is to be noted that the range of radiosensitivity is never more than a factor of 10, so that there is no "idiosyncrasy" involved. In other words there is no chance of an individual's being so extremely sensitive to radiation as to be harmed by what would ordinarily be called a safe dose.

Another important characteristic is that of recovery. The cells tend to recover after radiation damage at a fairly rapid rate. For example, to get the same effect as a dose of 600 roentgens administered at one time, a total

dose of 900 roentgens is required if it is administered half on one day and half the next day.

There are two general categories into which radiation damage may fall: one is surface effect, and the other a sort of volume effect, as caused by what is called "total body radiation." For the latter, of course, penetrating radiation is necessary.

In general, radiation damage to the skin is persistent, so that ulcerated places are likely not to heal and may become malignant. Some lesser effects are encountered, such as the production of little warts on the workers' hands. These do not grow laterally but continue to grow vertically, necessitating occasional "shaving," and they never disappear. It is apparently possible that these should some day become malignant, though so far this is not known to have happened.

It thus becomes highly important to prevent even these small but permanent local injuries. It is felt that if the skin is not damaged radiation-induced cancer will not occur. In general, however, no special precautions need to be taken for alpha or weak beta-emitting materials since particles from these will not penetrate the dead or outermost layer of skin.

Total body radiation causes damage by affecting the cells in the bone marrow which produce the blood cells. The worst thing that can happen is damage of these "mother cells" so that blood cells of a malignant type are produced. This results in leukemia, really cancer of the blood, which is inevitably fatal. The biological check on this kind of damage is the blood count, the most sensitive indication of this damage. If the blood count is unaffected there is presumably no radiation damage. The objection to use of this as a protective measure is, of course, that if the blood count does change the damage is already done.

TABLE 1

Particle	*Mass*	*Charge*	*Specific Ionization (Ions per micron of water)*
Electron	$\frac{1}{1800}$	−1	10– 150
Proton	1	+1	500–1900
Alpha particle	4	+2	3000–7500
Carbon	12	+6	>7500
Nitrogen	14	+7	>7500
Oxygen	16	+8	>7500

Thus it is advisable, in the case of total body radiation, to keep the exposure low enough so that such changes do not occur.

In general, although biological damage is proportional to the roentgen dose, the specific ionization, or ion density along the path of the particle, is also important. Particles with higher density of ionization generally have more biological effect. Table 1 shows the specific ionization for various particles, and Table 2 shows the best estimate of the relative biological effectiveness of various particles, in the light of present knowledge.

It is now felt that some changes in the present tolerance limit of 0.1 r per day are advisable, and proposals for revision of the permissible limits have been made. One objection to expressing the limit in terms of daily dosage is that a man who receives even a frac-

TABLE 2

Particle	*Relative Biological Effectiveness*
X-rays, gamma rays, beta particles	1
Protons	5
Alpha particles	10
Fast neutrons	10
Thermal neutrons	5

tion over the limit for one day and much less the rest of the time must be considered to be "overexposed." It is felt that a limit expressed in r per week would be more workable. It is also believed that the limit should be lowered somewhat, since the safety factor is not so large as was thought at one time. Not too much is known either of the possible effect of continuous exposure of 0.1 r per day over a period of, say, 25 years.

In view of these factors, it has been proposed that the limit be 0.3 r per week for total body radiation. In terms of the rep (roentgen equivalent physical), a unit which is the same as the roentgen for X-rays but for the other particles represents the amount which will do the same biological damage as a roentgen of X-rays, it can be stated slightly differently. The bone marrow shall not receive more than 0.3 rep per week. This, then, includes cases where there may be radioactive material in the body.

For local exposure (e.g., the hands) a slightly higher limit of 1.5 rep per week is proposed.

Finally, for possible emergencies, it is proposed that a man might be allowed to receive up to 25 r at once if under 45 years of age, or 50 r if over 45, total body radiation. After such an exposure a man should not receive further radiation.

* * *

Health Protection Instrumentation, by F. R. Shonka, *Argonne National Laboratory, Chicago, Ill.* All types of radiation to be measured depend directly or indirectly on ionization. During ionization the radiation loses energy to the medium in which it is absorbed. For example, in air approximately 32 volts are expended per ion pair produced. The greatest specific ionization is caused by α-particles, considerably less by β-particles and the least by γ-rays. The uniformity of ionization along the incident path is also great for α-particles and much less for β- and γ-rays.

The ionization due to γ-rays is caused by the primary ejection of photoelectrons from the gas molecules at the lower energies. At higher energies Compton electrons may also be effective and at still higher energies, pair production. In any case, the ionization due to γ-rays is caused mainly by secondary β-particles.

Since the biological effects of radiation result from the chemical changes induced in a cell by ionization, the unit of dosage, namely, the roentgen, has been defined in terms of charge produced by ionization as a result of the absorption of radiation. For γ-rays the unit is defined as that quantity of radiation which produces one electrostatic unit of charge per cc of air under standard conditions, when the incident γ-rays are in equilibrium with the secondary electrons. This equilibrium refers to the condition that the γ-rays and the secondary β-particles be absorbed at the same rate.

Since all other types of rays, including neutrons, ultimately are effective in causing ionization, a dosage of any type may likewise be measured in terms of the roentgen. The problem of the quantitative measurement of radiation is limited by the presence of an irreducible background. This is due principally to cosmic rays which are known to produce about 1 ion pair per cc of air per sec. These in turn release secondary electrons capable of further ionization which, together with that due to contamination by radioactive elements ordinarily present in all substances, produce about 6 ion pairs per cc of air per sec. This is equivalent to 0.00025 roentgens per day, due to natural causes, and sets a limit on the sensitivity of radiation measuring equipment.

The most sensitive type of instrument for accurate quantitative meas-

urement is the ionization chamber. The method of its use, despite many variations for improvement in its constructional and operational features, has remained essentially the same since its early introduction, namely that of calculating the charge produced in a known volume of air by measuring the charging rate of the known capacitance of the chamber.

Qualitative estimates of radioactivity make use of standard Geiger counters in conjunction with an electronic circuit capable of indicating the rate at which pulses are received. This is the well-known rate meter quite widely used as hand and foot counters and to check contamination on clothing and in air-conditioning systems, etc.

* * *

Proportional Counters, by Serge A. Korff, *New York University, New York, N. Y.* Proportional counters are gas-filled diodes operated at a potential just below the point of positive corona. Ionizing particles produce a local corona, which then extinguishes itself. The tubes are constructed with cylindrical symmetry because they are mechanically simple. Unfortunately however, this shape affords a wide difference in internal path lengths for the ionizing particles and hence produces a directional factor in the counter's sensitivity that needs to be taken into consideration or modified by external diaphragms.

The size of the voltage pulses produced by the counter in the presence of radiation is determined by (1) counter geometry, especially the diameter of the central wire (2 to 4 mils gives a tube of reasonable operating voltage) and (2) the gases in the counter, which can be anything, with those which form positive ions being preferred. Methane or boron trifluoride are used for neutron detection. The circuits associated with these counters are adapted to respond to pulses in the order of a tenth of a volt. The minimum energy particle to which a counter responds depends on the thinness of the entrance window.

The unique property of proportional counters is that they distinguish, by the amplitude of the output pulse, the nature of the ionizing particle. Alpha, beta and gamma rays produce progressively smaller pulses. An oscilloscope can be used in setting the discriminating (clipping) level for the energy of interest. One electron produces a pulse of about 10^{-8} volt; there is sufficient gas amplification to raise this to 0.01 to 1.0 volt and, of course, each particle produces many ionizations within the tube. Proportional counters are faster than Geiger counters; pulses can actually overlap, but they are paralyzed by high rates.

* * *

Neutron Detection, by B. T. Feld, *Massachusetts Institute of Technology, Cambridge, Mass.* There is a basic difference between the detection of neutrons and any other particle encountered in nuclear physics. The neutron, lacking charge, is incapable of ionizing matter directly and as a rule penetrates comparatively deeply before being absorbed or scattered. This means that an indirect phenomenon must be relied upon to detect a neutron. In certain elements, there exists a large probability that a neutron, in passing the vicinity of a nucleus, will be captured thereby, with the subsequent emission of a charged particle or gamma ray. It is the latter which is then counted by conventional means.

Neutron detectors may be placed in two categories:

1. Instantaneous detectors
2. Delayed detectors

In the first category are the various types of proportional counters and ionization chambers based either on the (n,α) reaction of B^{10} or on a heavy nucleus fission, induced, of course, by neutron absorption. The most com-

mon is the BF_3 proportional counter, whose construction is identical to the standard G-M counter but is filled with BF_3 gas at from 30 to 50 cm pressure. The absorption of a neutron by a boron nucleus causes almost instantaneous emission of an α-particle. The latter then causes the ionization which delivers the pulse. By operating in the proportional region, one can distinguish between the strong α-pulses and those due to a background of γ-rays which are often present. In order to obtain greater speed, one can fill an ordinary ionization chamber with BF_3 gas at atmospheric pressure and obtain the pulses due to the primary ionization of the emitted α-particles. This, however, requires greater electronic amplification. Neutron fluxes can be indicated by measurement of the average ionization current of such a chamber in the usual fashion. The efficiency of these detectors, which is low to begin with—because of the relatively low absorption of neutrons in the gas—can be enhanced by coating the walls of the detector with a thin layer of metallic boron.

The fission detector consists of an ionization chamber whose walls are coated with a fissionable element. The strong pulses due to the ionization by the fission fragments are quite easily detected, thus providing a reliable detector useful in monitoring neutron fluxes.

In the second category may be listed cloud chambers, photographic emulsions, and radioactive foils. In each of these cases, the results of the detection are delayed until a subsequent processing or measurement has been performed. The cloud chambers are filled with a neutron-reacting material. The tracks so obtained, however, bear no relation to the incident neutrons except insofar as the start of the track marks the spot where a neutron was absorbed. In the method utilizing photographic plates, the emulsions are impregnated with boron, lithium, or another element having a high neutron capture, and the tracks of the ionizing particle or photon resulting from the capture are then obtained on development. The foil techniques are used mainly in determining neutron fluxes and depend on the radioactivity induced in a metal foil by exposure for a specific time in a neutron beam. Usually an (n,γ) reaction is used such that the foil is made β-active. After the foil is removed, the β-activity may be measured and its strength gives an indication of the neutron flux to which it was exposed.

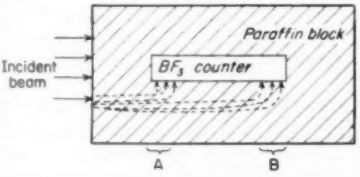
The choice of the particular technique of detection as well as variations in the methods of application are closely allied to the energy range of the neutrons being detected. Neutron energies may be separated, somewhat arbitrarily, into five ranges which are listed together with the most convenient methods of detection, as follows:

1. Thermal neutrons. These are neutrons which have the lowest energies and which have achieved equilibrium with the thermal motion of the atoms of some moderating substance, such as paraffin, water, or carbon, at room temperature. They have energies up to about 0.025 electron volts and can be easily detected by means of BF_3 counters, ionization chambers, cloud chambers, etc., as well as foils for which many (n,γ) reactions initiated by thermal neutrons are available. It is possible to measure thermal neutrons selectively in the presence of higher energy neutrons by making use of the selective absorption of a sheet of cadmium. The latter element absorbs neutrons strongly with energies below an absorption threshold in the neighborhood of 0.5 ev, above which it is fairly transparent. The difference in the activity of a foil exposed to a neutron beam with and without a cadmium

absorber will give an indication of the number of thermal neutrons present in the beam.

2. Resonance neutrons. This term applies to neutrons having energies from the thermal region to about 1,000 ev. The name is derived from the fact that a large number of elements exhibit the phenomenon of resonance absorption to neutrons in this energy region. These resonances are more or less sharp so that only a limited energy region can be covered by any one element. However, practically the entire range can be covered by suitable choice of the absorbing element. The type of detector used depends on what the product of the nuclear reaction, resulting from the absorption, happens to be. In any case the method consists of surrounding a standard particle or photon counter with a resonance absorber.

3. Intermediate neutrons. These have energies from 1 kev to about 1 Mev and, in general, are the most difficult to detect. It is necessary first to slow them down by means of paraffin or water to the resonance or thermal region before they can be counted. An arrangement which is capable of detecting intermediate neutrons with a sensitivity substantially independent of energy over this range is shown in the figure:



The lower energies penetrate only a relatively short distance into the paraffin block before they are slowed down by successive collisions to thermal energies where they then can diffuse laterally into the BF_3 counter, e.g., at the point *A*. The higher energy neutrons in this beam will penetrate much deeper before they are slowed down sufficiently to be detected by the counter at the point *B*. Inasmuch as the sensitivity of the BF_3 counter is independent of the point at which the neutron enters the counter, all energies between the two groups will be detected with equal sensitivity. It is obvious that efficiencies in this region will be quite low because of the fact that a large number of incident neutrons never reach the counter.

4. Fast neutrons. Neutrons having energies from 1 Mev to about 20 Mev are termed fast neutrons. These can be conveniently detected in two ways. The first depends on the fact that fast neutrons impart a considerable fraction of their kinetic energy to protons upon collision. The recoil protons then have sufficient energy to be detected easily by standard means. Thus, an ordinary counter filled with methane gas and operated in the proportional region (to distinguish from a γ-ray background) would detect neutrons of these energies. Or an ordinary counter, having walls thin enough to admit the recoil protons, and surrounded by a thin layer of paraffin, would serve equally well. The second method is based on fission induced by fast neutrons. U^{238} has a fission threshold in the neighborhood of 1 Mev, above which the absorption of neutrons due to fission is fairly high. The fission fragments are energetic enough to be detected by almost any means desired.

5. Ultra-fast neutrons. In this last group are placed neutrons having energies above 20 Mev. These are likewise detected both by recoil protons and fission chambers. For ultra-fast neutrons, the cross section for neutron-proton scattering goes down so that the efficiency of production of recoil protons from a given thickness of hydrogenous material is reduced. However, this is somewhat compensated for by the fact that the angular distribution of the recoils with respect to the inci-

dent beam is more favorable. That is, they tend to come out more in the general direction of the incident beam, so that the reduced efficiency of production can be mitigated by suitable positioning of the counter. The element bismuth has a fission threshold at about 60 Mev, so that a fission chamber whose walls are lined with bismuth is an excellent device for detecting neutrons in excess of this energy.

* * *

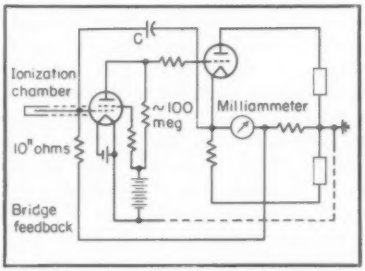
Ionization Chambers, by J. A. Victoreen, *Victoreen Instrument Co., Cleveland, O.* The gold-leaf electroscope has evolved into the ionization chamber, in which an applied charge escapes due to ionization of the surrounding gas by the radiation to be measured. Photoelectric emission also permits the charge to escape. The unit of radiation, the roentgen, is defined in the region from 0.5 to 1.0 Angstroms in terms of the charge produced by ionization in air, air having about the mass and atomic number of the human body, in which early X-ray operators were interested. In constructing small chambers for wider energy ranges, care must be taken to avoid excessive effects due to the chamber walls. The chamber must be large enough so that the radiation will expend itself entirely at high energies and the walls thin enough so that low energies can penetrate the chamber. Hence, chambers should be calibrated against standard chambers. The effect can be mitigated somewhat by making the walls of a material (carbon) having an atomic number close to the average for air.

* * *

Ionization Chamber Measurements, by E. W. Molloy, *National Technical Laboratories, S. Pasadena, Calif.* In using ionization chambers for measurement, the problem is to develop circuits especially for health survey meters, that respond to currents from 10^{-14} to 10^{-18} ampere, are light, sturdy, have long battery life and are easily operated and serviced. Modern circuit methods, using negative feedback, permit making the circuit response nearly independent of tube parameters.

Two, or at most three, electrometer tubes can be built into portable equipment. The output tube is operated as a cathode follower so that high-torque (sturdy) indicating instruments can be used and so that the calibration will be less dependent on battery voltage. The first tube is operated as an electrometer with its grid held, by feedback, at nearly constant potential. The feedback also decreases the time constant, reduces drift and increases linearity.

With a fully pumped tetrode, the required performance can be obtained by operating the coated cathode at 60% of its rated current, the grid just enough negative to avoid electron collection, the screen and plate at low voltages with currents in the microamperes and a plate resistance of 100 megohms. Grid current is then 10^{-14} ampere and the gain is from 100 200. to Silicon oils have made the necessarily high vacuum for such tubes possible.



The diagram shows a conventional circuit for this sort of application. The drain on the high-voltage battery is so low that the battery lasts about its shelf *life*. The bridge feedback maintains the input grid at ground potential, thus reducing the insulation problem and time constant. The phase

margin can be corrected by full loop capacitance through C, and additional feedback could be provided along the dotted line. Because of the low loop gain, the cathode follower is necessary for stability. Full scale deflection is produced by this amplifier at 5×10^{-13} ampere ion current. It has a time constant of 3 to 5 seconds on its most sensitive range; response is faster on less sensitive ranges.

* * *

Stabilized Voltage Supplies, by W. A. Higinbotham, *Brookhaven National Laboratory, Upton, Long Island, N. Y.* The average current required by counters and chambers is at most a milliampere, including bleeder current. Ionization chambers do not require stabilized supplies. Proportional counters need low noise supplies and voltage stability to 0.1% per hour. Geiger-Müller tubes are not critical as to voltage stability or noise. Photomultipliers, on the other hand, require highly regulated supplies. All types of regulators are used. For laboratory and portable equipment, batteries are used, but they become noisy with age. A regulated supply costs about 5¢ per volt.

In supplies for power-line operation, the transformer is the weakest link, especially its insulation. Power lines give from 90 to 135 volts and have small static voltages. For rectification a tube or disk stack can be used; an *R-C* filter is sufficient for initial smoothing.

The most popular regulator is the degenerative type. The high-voltage resistors necessary in this circuit, if of the composition type, are not satisfactory at high power; instead several radio resistors can be used in series. Voltage regulator tubes are not accurate to the several tenths of a percent necessary in some applications. In addition, changes in contact potentials of the grids of the amplifier tubes in the regulator with changes in their heater currents limit the accuracy.

Chains of gas regulator tubes are used. The shunt regulator can be used. The mu-balance regulator requires rebalancing for new tubes; the mutual-conductance regulator has limited range. Radio-frequency supplies are light in weight and avoid noise from transformer and rectifier, but have high internal impedance and so need protection from humidity—a regulator should be used in the d-c supply to the r-f oscillator. The pulse-type supply has no particular advantage over the r-f type and is critical with regard to waveshape. Saturable or controlled reactors or oscillating switches charging banks of capacitors in parallel and discharging them in series have been used.

Usually the regulator is followed by additional filtering, but caution must be observed because some capacitors are noisy. In designing the supply attention must be given to the surge when the power is turned on (a slowly heating rectifier filament would be useful) and to safety; 2 μf at 5,000 volts is lethal, r-f supplies are easily made safe.

* * *

Cloud Chambers, by G. C. Baldwin, *General Electric Company, Schenectady, N. Y.* Because cloud chambers give the spatial distribution of ions formed by a nuclear particle, they give more fundamental information than do other detectors. The ions formed in the chamber are, in effect, amplified by preferential moisture condensation on them. The momentum of a passing particle is transferred to an atomic electron in proportion to the particle's charge squared and to its mass, and inversely to its velocity squared. Thus the density of the track indicates the nature and state of the particle.

The tracks formed in the gas of the chamber, which may be air, water vapor or alcohol, are photographed using xenon-filled flash lamps, an f-2 lens

and Super-X film through a mirror arrangement that gives a stereoscopic view. The negatives are then reprojected through a duplicate optical system to produce an oriented image in space that can be located by properly tilting a ground glass to obtain the exact direction of the track. In this way precise determinations of momenta associated with a collision can be made.

This equipment at the General Electric research laboratory is arranged by automatic controls to go through its cycle once a minute. Thirty seconds before expansion, a magnetic field of 40,000 gauss is applied for the duration of the exposure. In cosmic-ray work, it is common practice to control the chambers by coincidence counters mounted on either side of the chamber to operate it when a ray arrives. Special chambers are built for high or low pressure or for high speed, in which case helium is used as the gas to permit reaching thermal equilibrium quickly.

In evaluating the evidence from the chamber, (1) the intensity of the track indicates the number of ions produced, (2) its curvature in a magnetic field shows the ratio of charge to mass of the passing particle, and (3) the length of the track shows the total particle energy. The chamber is used to observe nuclear particles and reactions. The presence of neutrons is deduced from the need for conservation of energy in a nuclear reaction. Greater energy ranges than possible with just the chamber gas are obtained by inserting foil partitions.

* * *

Electron Multiplier Counters, by P. S. Johnson, *Bureau of Ships, Navy Dept., Washington, D. C.* By placing a phosphor over the window of an electron multiplier tube, a sensitive nuclear detector is obtained that holds interesting possibilities as a portable survey-type instrument. Nuclear particles produce light scintillations in the phosphor that are received and amplified by the phototube.

The first consideration in making such counters is the phosphor. Naphthalene and anthracene are the most important of the organic phosphors, the latter being the more sensitive (P. R. Bell of Oak Ridge has grown large crystals of it, which he polishes and coats with a reflecting backing to direct as much light as possible into the phototube, thus getting an additional improvement of two). Transtilbene is fast; phenanthrene is also used. Although inorganic phosphors such as calcium tungstate ($CaWO_4$), sodium iodide with thallium activation (NaI-Tl) and potassium iodide (KI-Tl) are slower than the organic ones but are more durable. Silver-activated zinc sulfide (ZnS-Ag), if thin, is useful for alpha detection; the problem with it is to encase the phosphor and phototube in a light shield than does not absorb the alpha rays.

The second consideration is the multiplier tube. The 1P21, which is the selected ten percent of the 931-A's having low noise and stable sensitivity, is frequently used. The amplifier into which the tube works is simple; it brings the level up to that required to operate a meter and discriminates against background. Using a coincidence technique with two tubes observing one phosphor, G. A. Morton at RCA gets 20 to 50 times the sensitivity of a G-M counter for alpha particles. Equal sensiiivity for the other particles is desirable.

* * *

Scintillation and Crystal Counters, by Robert Hofstadter, *Palmer Physical Laboratory, Princeton University, Princeton, N. J.* SCINTILLATION COUNTERS: Potassium iodide and sodium iodide emit light in a wavelength band in which the absorption is very low. That a phosphor should not absorb its own

light is of course very desirable for scintillation counter work, since large pieces of phosphor may then be used if they are optically clear.

The earliest samples of thallium-activated NaI were prepared by torching NaI and TlI in a small quartz tube. This produced many small clear crystals of the order of a few millimeters on a side. The crystals were left in the tube during use because they are very hygroscopic. Subsequent refinements in technique have made it possible to produce larger clear crystals, and methods of coating the crystals to protect them from moisture are being studied.

The length of the light flash from the phosphor is of the order of 1 microsecond. However, both the size of the pulse and the time duration are functions of temperature.

In general the NaI gives pulses in the equipment several times the size of those from anthracene, the presently best of the organic phosphors. It is estimated that the NaI will produce about 30 photoelectrons per Mev (of the incident radiation) from the cathode of the photomultiplier tube, while anthracene may produce about 15 photoelectrons per Mev. In such a counter, there is a wide distribution of pulse sizes observed. The counter may be set to record only pulses greater than a chosen size; this is the discriminator, or "bias" setting. If a plot is then made of counting rate at different bias settings, the pulse size distribution can be obtained. The counting rates at any bias setting are higher for NaI than for anthracene, and much higher than for napthalene. One set of curves showed that the pulse sizes vary with the energy of the incoming radiation, so that the number of counts per minute at a given bias setting will be larger if the energy of the incoming particle is greater. Although there is always a distribution in pulse sizes observed in these counters, the average pulse size is considered to be directly proportional to the average energy per particle dissipated in the phosphor, other things being equal.

CRYSTAL COUNTERS: That certain crystals could be used as counters was first demonstrated by P. J. Van Heerden in 1945. Electrons released in the crystal lattice by an incoming particle move across the crystal under the influence of an externally applied field, and this movement may be detected, as a short current pulse, by means of suitable circuits. If the electron moves only a short distance Δx in the crystal and is then "trapped," the charge delivered per electron to the electrodes on the crystal surface will be $\Delta x e/l$, where e is the electronic charge and l is the crystal thickness. In these crystals it has been found that about 8 ev are required to release one electron. It is to be noted that there is no multiplication in these counters corresponding to gas amplification in a G-M counter.

Diamond, ZnS, and CdS will operate as crystal counters at room temperature. Diamond is quite good, but it is understandably hard to get proper specimens, ZnS is not so good, and CdS has some peculiar characteristics which have not been completely explained.

AgCl, AgBr, TlBr, and TlI will all work at about liquid air temperatures. Of these, the best, and the easiest to handle, seems to be AgCl, the material used originally by Van Heerden.

Since the pulses from the crystal are small even under the best of conditions a high-gain amplifier is required to amplify the signals for the recording, or measuring equipment. Except for three crystals that work at room temperature provision must be made for cooling the crystal to liquid air temperature. In addition AgCl, at least, must be kept from the light, must be kept from contact with metals which might

poison it, and also seems to work best in a vacuum.

The crystal itself should be a single crystal, and should be very pure, or at least should have a minimum of electron traps of the sort produced by impurities and crystal boundaries. That this is important can be seen from the equation given above for the charge delivered per electron. If there are many traps the value of Δx will be small, and the observed pulses also small. For this reason elaborate techniques have been used for growing large, single, pure crystals, and for subsequent treatments such as annealing.

The crystal counter is not then too attractive as a practical instrument because of these many complications. Nevertheless, it has certain characteristics which make it useful as a laboratory instrument. By use of large crystals a high stopping power may be obtained. It is quite fast. The pulses have a rise time depending on the applied field; in typical cases this is of the order of 1 microsecond. Finally, the pulse size is proportional to the energy dissipated in the crystal. Under certain circumstances such a counter can be very useful.

One further complication is introduced by space charge effects in the crystal. When an electron moves it leaves behind a positively charged "hole." After about a million counts the space charge due to these "holes" will create enough of an opposing electric field to render the crystal insensitive. Annealing the crystal will restore the sensitivity, or in the case of gamma radiation the space charge may be essentially neutralized by periodic field reversal.

* * *

Electronic Counting Techniques, by Matthew Sands, *Massachusetts Institute of Technology, Cambridge, Mass.* A nuclear electronic detector feeds a pulse amplifier that drives electronic counters to form the basis of the counting technique. The fundamental problems in designing equipment for this technique are (1) to obtain the maximum information from each test and (2) to use inherently stable circuits. The data of interest to nuclear physicists include both the number of incident particles and their energies; thus the pulses should not only be counted but discriminated as to amplitude. Pulses between two amplitude limits can be selected by differential discriminators ahead of a counter. By arranging the equipment to catalogue the pulses by amplitude, much data can be obtained from each run.

Discriminators can be made using infinite-gain trigger circuits, preferably arranged so that their outputs are of constant amplitude, and having an abrupt nonlinearity at the level of interest. Firing time can be controlled with sloping pulses to provide amplitude discrimination.

* * *

Photographic Emulsions for Use in Radiation Measurements, by J. Spence, *Eastman Kodak Company, Rochester, N. Y.* All nuclear detectors make use of amplification of some form; in photographic phenomena the amplification is obtained by the catalytic development process. If absolute results are to be obtained, because of the variations in emulsions and processing, a control film should be used with each lot of test film. The requirements for nuclear emulsions are uniform grains and high sensitivity; silver halide concentration is made higher to obtain recognizable tracks. Heretofore, films for use in X-ray technology were the only large application. To provide films for the extended nuclear studies, further development is being made. A film so sensitive that the background cosmic rays would fog it in a week (before it could be shipped to the customer) has been made experimentally.

Density Correction in Beta-Ray Assaying of Rock and Mineral Samples

The beta activity of a number of minerals mixed with uranium, thorium and potassium, in constant proportion, has been measured. It has been found that the apparent density correction for samples of varying densities is of a significant magnitude

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THE DETERMINATION of relative content of radioactive material in rock samples by measurement of their beta activity, first mentioned by Pontecorvo,* has become a widespread technique in geology as well as in mineral exploration. The increasing use of the method largely can be ascribed to its relative simplicity and consequent reliability. The chemical methods of analysis for potassium, thorium, and particularly uranium are costly and slow. Beta-ray assaying with chemical control is frequently adopted when large numbers of samples are to be tested. The necessary electronic equipment is not too complex and is now readily available from several manufacturers.

The usual procedure is to place a fixed volume of the finely crushed rock sample in the immediate vicinity of the sensitive region of a thin-wall or mica-window beta counter, as shown in Fig. 1. The thickness of the sample is usually chosen to be somewhat greater than the maximum range of the most energetic beta ray emitted from the sample to be measured. In this way the recorded activity will consist almost exclusively of beta rays. The gamma radiation of the sample will have little effect due to the low efficiency (on the order of 1%) of Geiger-Müller counters for gamma rays. Even though some mica-window counters are sufficiently delicate to admit and count the more energetic alpha rays, the self-absorption of alphas in the sample is usually great enough to make their contribution also negligible.

The method has been used by Barnes and Salley† for analysis of potassium solutions, by Beers and Goodman‡ for rock samples, and by numerous other investigators. Beers and Goodman have observed that the beta activity of a sample depends, to a certain extent, on the density to which the sample is packed when placed under the counter. For convenience we may refer to this parameter as the *apparent density*. They prepared three samples of different apparent densities, but containing U_3O_8 in identical proportion by weight, and found the specific counting rate (counts/minute-gram) of the samples was a linear decreasing function of the apparent density. Barnes and Salley had previously observed the same effect, but concluded that the specific counting

* B. Pontecorvo, *Geophysics* **1**, 90–94 (1942).

† Barnes, Salley, *Ind. Eng. Chem., Anal. Ed.* **15**, 4–7 (1943).

‡ Beers, Goodman, *Bull. Geol. Soc. Am.* **55**, 1229–1254 (1944).

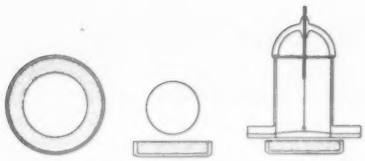

FIG. 1. Sample geometries commonly used in beta-ray assaying: *A* and *B* thin-wall counters, *C* mica-window counter. *A* is a cylindrical sample surrounding a cylindrical counter; *B* is a cylindrical counter in a horizontal position, placed above the sample contained in a shallow cylindrical tray. Similar tray is used in *C*

rate is a logarithmic function of the density of their potassium solution. Similar observations have been made by one of the authors,* in general agreement with Barnes and Salley. It is clear that the apparent density correction is important in the beta-ray assaying of samples of diverse densities. An investigation of the effect on the activities of the uranium and thorium series, as well as potassium, has been carried out, and it is the purpose of this paper to report the results of the study.

Samples, Apparatus and Procedure

Uranium, thorium (in equilibrium with their daughter products) and potassium were investigated in dilute mixtures with radioactively inert minerals and metals. The diluents, arranged in the order of increasing apparent density, were as follows:

Halite	Barite
Anthracite	Sphalerite
Kaolin	Magnetite
Calcite	Magnetite-iron powder
Quartz	(50-50 mixture)
Fluorite	Iron powder
Olivine	Galena
Pyrite	Tungsten powder

The uranium samples were prepared by mixing the diluents with pitchblende (Eldorado jig and table concentrate) in constant proportion of 0.43% U_3O_8 by weight. Canadian pitchblende was chosen because it is geologically unaltered and has a very low emanating power. The decay products of uranium are, therefore, in almost complete equilibrium. Indian monazite was used for the thorium samples which were mixed to contain approximately 0.4% ThO_2. The potassium samples were mixed with potassium chloride, U.S.P., and contained 12% K_2O. All samples were ground to pass 80 mesh, but the kaolin and tungsten were finer than 400 mesh.

A modern self-quenching mica-window counter with a window diameter of 2.7 cm and a window thickness of 2.0 mg/cm² was used in the experiments. The counter was surrounded by a minimum thickness of 5 cm of lead.

The powdered samples were poured into round brass trays 3.43 cm in diameter and 0.48 cm deep, leveled off with a straight-edged spatula and placed under the counter with the leveled surface 0.2 cm below the mica window. The leveling operation merely removed all excess powder but did not appreciably compress the sample. After each beta-ray determination the sample was weighed to determine its apparent density.

The counting rates were recorded with an automatic scaling circuit designed to measure the length of time required to collect a pre-selected number of counts. This procedure has the advantage of constant statistical error. For each point on the uranium curve, 20,480 counts were collected, 16,384 for each thorium determination, and 2,048 for each potassium assay. These figures were chosen purely for convenience of operation, giving the following probable errors:

Uranium curve	± 0.5%
Thorium "	± 0.5%
Potassium "	± 1.5%

The actual experimental error is estimated to be about twice the statistical

* H. Faul, AIME. Tech. Pub. 2460, *Mining Technol.*, Nov., 1948.

probable error and the weighing error is less than approximately 0.2%.

Results

The results of the measurements, plotted on semilog coordinates, are shown in Fig. 2. It will be seen that the points fall on a line that does not follow a simple function, although the logarithmic law proposed by Barnes and Salley (*op. cit.*) for potassium solutions is a good approximation for the lighter minerals. The curve is the sum of two competing effects: first, the number of radioactive nuclei present in a volume of sample of a given grade is obviously directly proportional to the apparent density of the sample, and, second, the self-absorption of the radiation from the sample increases with increasing apparent density. Chemical composition of the diluent material in the sample has no effect, for the mass absorption coefficient for beta rays is nearly independent of the atomic weight of the absorbing elements.

It is interesting to note that the uranium and thorium curves are almost exactly parallel. The potassium curve is slightly steeper at apparent densities lower than about 1.0, for the potassium beta is less energetic on the average than the mean of the *effective* beta spectra of the uranium or thorium decay series.

The shapes of the curves are probably independent of the absolute grade of the sample or the exact geometry of the counting setup. Previous measurements by Beers and by Faul are also shown in Fig. 2. For comparison they are normalized at $\rho = 1$. The present measurements are in excellent agreement with the previous results, even though Beers used samples containing only about 0.0005% of uranium (as carnotite), in a large coaxial (Fig. 1*a*) aluminum-wall beta counter and Faul used carnotite, containing about 0.7% U_3O_8, with a thin glass-wall counter in

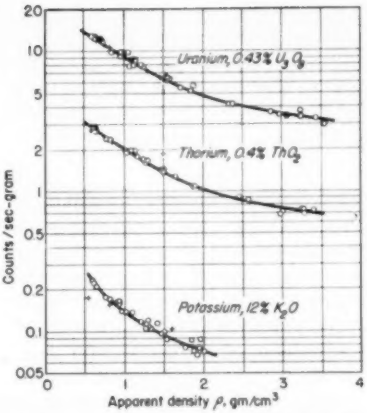

FIG. 2. Specific counting rate of samples containing uranium, thorium, and potassium in fixed proportion, plotted against the apparent density of the samples (open circles). Previous measurements by Beers (crosses) and Faul (solid circles) are shown, normalized at $\rho = 1$

a geometry shown in Fig. 1*b*. The geometry of the present measurements is shown in Fig. 1*c*.

One may also compute the ratios of specific counting rates for the three radioactive *elements*, from the data presented above:

$$U/Th = 4.2$$
$$Th/K = 475$$
$$U/K = 1940$$

In the common language of the assay chemist:

$$U_3O_8/ThO_2 = 4.3$$
$$ThO_2/K_2O = 450$$
$$U_3O_8/K_2O = 1900$$

These figures are approximate, and will vary from one counter to another, but they serve to illustrate one of the inherent difficulties in beta-ray assaying. A given proportion of U_3O_8 in a sample will give a counting rate about 1,900 times greater than the same proportion of K_2O. Consequently, a small uranium impurity will introduce an appreciable error in the beta-ray assay of a potassium-bearing mineral;

a large content of potassium, on the other hand, will increase the activity of a uranium sample only slightly. This relation is important because uranium and potassium are frequently associated in rocks.

Conclusion

The apparent density correction in beta-ray assaying is an important factor where samples of diverse densities are analyzed. A good calibration curve can be obtained by measuring two or three samples of identical radioactive content but widely different density and interpolating between these points with the aid of the data here presented.

* * *

The authors would like to acknowledge the help and encouragement received from Professor W. L. Whitehead of the Department of Geology, MIT, under whose direction this work was done. The research was sponsored by the Geological Society of America through a grant-in-aid from the Penrose Fund for a three-year investigation of the radioactivity of various sedimentary formations.

MODEL OF NUCLEAR STRUCTURE

Protons are represented by floating magnets, and neutrons by floating soft-iron rods. The forces between these floats qualitatively simulate those active in building real nuclei, and the model appears to have distinct educational value

By C. J. MILNER

The British Thomson-Houston Company, Ltd.
Rugby, Warwickshire, England

DURING PREPARATION of a semi-popular lecture on atomic energy, need was felt for a concrete representation of the structure of atomic nuclei. The model here described, conceived in the course of attempts to become familiar with current theoretical views of the nucleus, has seemed a useful, if imperfect, simulation of the principles involved. The hope, in publishing this description, is that others also may feel their understanding improved by a visible and tangible model; its deficiencies are so obvious that no one, it is hoped, will be misled into believing that nuclear structure can be visualized at all.

The model employs floating magnets and in this respect resembles the atomic model used by J. J. Thomson and ascribed* by him to the American physicist, Mayer. "Mayer's magnets" simulated electrons in static equilibrium in the extended positive-sphere atom concept favored by Thomson, later displaced by the Rutherford scattering results. Magnets floating in water set themselves, under the influence of a central attractive force set up by a fixed electromagnet and their own mutual repulsion, into an array of rings which

* J. J. Thomson, "The Corpuscular Theory of Matter," p. 110 (Constable, London, 1907).

develops, as more magnets are added, in a manner suggestive of ascent through the periodic table of the elements. In the present model floating magnets are also employed. Their mutual repulsion is now balanced, however, by their attraction to floating soft-iron rods, and no fixed central magnet is used. The grouping of the floats in "floating islands" roughly copies the binding of protons and neutrons into complex nuclei.

Principles of the Model

The present theory of the constitution of the atomic nucleus appears to include the following basic features:

1. Nuclei are built of protons and neutrons.
2. Protons carry unit positive charge, and repel one another with a Coulomb force ($\propto r^{-2}$, energy $\propto r^{-1}$).
3. Neutrons carry no charge and do not interact with one another.
4. A proton and neutron attract one another with a force of short range [energy has by some been taken as $\propto r^{-1} \exp(-\lambda r)$ where $\lambda^{-1} \approx$ radius of proton or neutron].
5. This attractive force is saturating in character (*i.e.*, a second proton or neutron is less strongly attracted to a pair already formed).

At least these characteristics are all represented in the model to be described. Protons and neutrons are modeled by floats in a trough of water carrying, respectively, vertical bar magnets and vertical rods of soft iron.

The magnetic moments being all parallel (none antiparallel), the magnets all repel one another, as protons do. The repulsion is, however, $\propto r^{-2}$ at small distances, falling off more rapidly at distances no longer small compared with the length of one magnet. While allowing that this law of force is quantitatively different from (2) above, it is suggested that the decreasing rapidity of variation of repulsion with distance as the distance is made small does qualitatively simulate the short-range attractive force which is held to exist in addition to, and to modify, the Coulomb force between protons in nature.

The soft-iron rods do not interact (except through their magnetization by fields due to a model proton or an external source, in which case they repel one another). The oppositely directed moment induced in a soft-iron rod by a magnet causes an attraction between rods; this decreases more rapidly with increase of separation, r, than does the above repulsion between two magnets, because of the dependence of induced moment on inducing field.

If the float diameter permitted very close approach, the flux of the magnet would be almost completely short-circuited by the rod. The combination would then not exert further forces, *i.e.*, saturation of the attractive force would be complete. To correspond with the fact that saturation is not complete (and that nuclei more complex than the deuteron exist) a finite float diameter is used, so that an appreciable residual field is associated with a pair, and further "neutrons" and/or "protons" will then attach themselves to the "deuteron" constituted by the pair.

Constructional Details

A suitable non-magnetic trough was made from the top portion of a domestic washing-machine bowl pressing, by welding on a flat aluminum bottom to form a regular-octagon vessel 21 in. in diameter, and 6 in. deep. This was filled with tap water to a depth of 4 in.

The floats were made by hand, glass blowing from borosilicate glass (B.T.H. C.9) tubing of 13.5–14 mm outside diameter, 0.75 to 1 mm wall thickness. One end of each was closed and blown hemispherical; the other end was joined to a similar tube of 5.5 to 6 mm diam-

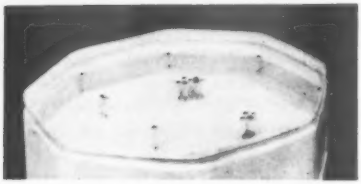

FIG. 1. Model of nuclear structure using floating magnets

eter, with as sharp a shoulder as possible where the diameter changed. There was thus formed a small bottle or flask with a bulb 14 mm diameter and 70 mm long, and a neck 6 mm diameter and 15 mm long. Ten mm of the neck nearest to the bulb were then softened in the flame and squeezed to a square cross section just over 1/8 in. × 1/8 in. *internal*, leaving the end 5 mm circular. Such a glass blank weighs 5 ± 0.5 gm.

The magnets used for model protons were 2 in. × 1/8 in. × 1/8 in. rectangular bars of Alcomax II.* These were slid into the floats and retained axially by the square "dimple" in the neck. Wax was melted into the circular end portion of the neck covering the end of the magnet, which was about 1 mm inside the neck. The "soft-iron rods" used for model neutrons were bundles of 9 pieces 2 in. × 1/8 in. × 0.014 in. transformer steel mounted in the same way as the magnets.

Both assemblies weighed 9.5 ± 0.5 gm each. They floated in water with about 8 mm freeboard.

The general setup is illustrated in the photograph, Fig. 1, in which a number of typical "nuclei" can be seen.

Simulation of Nuclear Reactions

Three "protons" and three "neutrons" can easily be assembled into a floating island which is a model of $_3Li^6$. By adding another "neutron," and vigorously forcing in another "proton," or by forcing in a "deuteron," held vertically and at the height at which it would float freely, the "compound nucleus," $_4Be^8$, is formed. There is experimentally about 10% probability for the disintegrations observed by Cockcroft and Walton in their classic experiments, demonstrating the nuclear reactions

$$_3Li^7 + {}_1H^1 \rightarrow {}_4Be^8 \rightarrow {}_2He^4 + {}_2He^4$$

and

$$_3Li^6 + {}_1H^2 \rightarrow {}_4Be^8 \rightarrow {}_2He^4 + {}_2He^4$$

Friction in the model permits several "isomeric states" with different (static) arrangements of the "protons" and "neutrons" all to exist stably. Some of these for "lithium" are illustrated in Fig. 2. The most stable "states" are those nearest to a circular arrangement; when these are "bombarded" as above, the $_4Be^8$ initially formed is not disrupted.

As in nature, nuclei in the model are progressively less stable as the mass number is increased. Unfortunately, the model does not exhibit beta transformations (or *K*-electron capture) and so for a given mass number there is a wide range of stable "proton-neutron" ratios. It is clear that the identity of

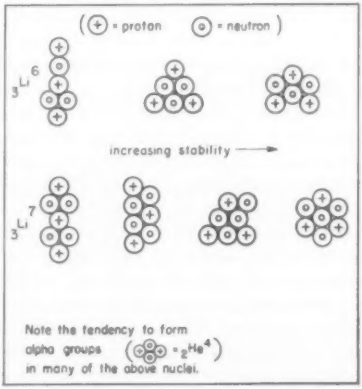

FIG. 2. Some "isomeric states" of "lithium" found in the model

* These were supplied by Messrs. Marrison and Catterall Ltd., 109, Kingsway, London W. C. 2.

a particle as, say, a "proton," is fixed in the model as long as the magnet remains magnetically undisturbed. (But perhaps when account is taken of the altered time scale, by which the $_4Be^8$ in the above example persists for $\approx 10^{-1}$ sec instead of only about 10^{-20} sec, transformation of a "proton" into a "neutron" by spontaneous segregation of the constituents of the magnet alloy ought not to be asserted as impossible if one waits 10^7 or 10^8 years for it!) With mass numbers of 40 to 50, decreasing stability against "proton," "deuteron," or "alpha-particle" emission with increasing mass number is apparent; indeed, occasional examples of fission into two or three "nuclei" of mass number 10 or more, together with a few isolated "nucleons," have been observed under "proton bombardment" as described above. Sufficiently energetic bombardment with "neutrons" (as with any kind of objects) will of course disrupt any "nucleus;" but repeated attempts have failed to simulate fission with slow "neutrons."

Conclusion

This model, while only two-dimensional and in other respects only qualitative, does illustrate many of the elementary facts about the structure of real atomic nuclei, and is thought to have distinct educational utility.

It was displayed in the Research and Educational Section of the Physical Society's Exhibition of Scientific Instruments and Apparatus in London, and was found to provoke a good deal of interest.

* * *

The author is glad to acknowledge the assistance of D. G. Smith in the detailed design and construction of the model; and to thank L. J. Davies, director of research, The B. T. H. Co. Ltd., for permission to publish this description of it.

Experimental Engineering Research Methods

Development should not be confused with research. In development, the end is a product, not an answer to a problem. A product may be developed solely by cut-and-try methods, but frequently research must be employed.

Development men must be practical, ingenious, and resourceful. They should have shop and operating experience and a sense of fitness in producing a salable product. In contrast, research men must be of the analytical type and well grounded in basic ideas, especially in physics and mathematics.

Requirements for research engineers include:

1. **An analytic type of mind and training in mathematics, physics and chemistry. A prodigious memory is not necessary and may be a handicap. An understanding of basic engineering phenomena is a needed qualification.**
2. **Specialization in at least one field for greatest usefulness.**
3. **Previous experience as a test engineer. This is necessary only for experimental research, not for paper research.**

—*C. E. Lucke*, Mechanical Engineering **70**, *793 (1948)*

NUCLEONIC EVENTS

13 VOLUMES OF NUCLEAR ENERGY SERIES ANNOUNCED

Thirteen volumes of the National Nuclear Energy Series have been declassified and are being edited for early publication, according to an announcement by the Atomic Energy Commission. It is expected that the series when complete will run to about 60 volumes.

The National Nuclear Energy Series is being published by the McGraw-Hill Book Company under a contract with Columbia University, which represents the AEC and its research contractors. The first volume, now ready for release, is the "Histopathology of Irradiation from External and Internal Sources," edited by William Bloom, Department of Anatomy, University of Chicago.

The volumes which make up the NNES are grouped in eight divisions corresponding to the major projects under which wartime atomic energy research activities were conducted. A list of these divisions and the books in each in final stages of editing follows:

Division I: ELECTROMAGNETIC SEPARATION PROJECT. Editor, R. K. Wakerling, University of California Radiation Laboratory.

Volume 5, *Characteristics of Electrical Discharges in Magnetic Fields*, edited by Dr. Wakerling. This book deals with the fundamental behavior of electrical discharges in magnetic fields. The studies were made in connection with the development of the calutron, the basic unit required for separating electromagnetically the fissionable isotope of uranium from ordinary uranium.

Divisoin II: GASEOUS DIFFUSION PROJECT. Editor, George M. Murphy, New York University.

Volume 16, *Engineering Developments of the Gaseous Diffusion Project*, edited by Manson Benedict, Hydrocarbons, Inc., New York, and C. Williams, Brookhaven National Laboratory. Deals with many of the unusual engineering problems encountered in the design and operation of the gaseous diffusion plant for the separation of uranium isotopes at Oak Ridge.

Division III: SPECIAL SEPARATIONS PROJECT. Editor, George M. Murphy, New York University.

Volume 1, *The Theory of Isotope Separation*, by Karl Cohen, H. K. Ferguson Co., New York. Discusses the basic theory of isotope separation by cascades or the repeated processing of material through many similar stages; also gives application of this theory to various types of isotope separation methods.

Volume 2, *The Spectroscopic and Photochemical Products of Uranium Compounds*, edited by G. H. Dieke, Johns Hopkins University, Baltimore, Md., and A. B. F. Duncan, University of Rochester, N. Y. Describes detailed investigations of the photochemical properties of various uranium compounds. The book is a fundamental contribution to the field of photochemistry, the branch of science concerned with the effect of light and other types of radiant energy upon chemical changes.

Volume 4, *Heavy Water*, edited by Harold C. Urey, Institute of Nuclear Studies, University of Chicago, and I. Kirschenbaum, Standard Oil Refinery, Elizabeth, N. J. Contains heavy water data and a very exhaustive study of all phases of the science and technology of deuterium (heavy hydrogen) and its compounds by the Manhattan Project.

Division IV: PLUTONIUM PROJECT. Editor, Robert S. Mulliken, University of Chicago.

Volume 19B, *The Thermodynamic Properties of Uranium Compounds*, edited by Lawrence Quill, Michigan State College, East Lansing, Mich. A detailed study of the thermodynamics of uranium and its compounds.

Volume 20A, *Industrial Medicine*, edited by Robert S. Stone, University of California. A description of the methods which were used so successfully to study and cope with the new hazards presented

by the work with plutonium. Dr. Stone was responsible for the health physics program of the wartime Plutonium Project.

Volume 22I, *Histopathology of Irradiation from External and Internal Sources*, edited by William Bloom. Gives detailed information about the effects of radiation from various sources on the structure and function of many types of body tissue. Fully illustrated.

Division V: LOS ALAMOS PROJECT. Editor, R. C. Smith, Los Alamos Scientific Laboratory.

Volume 1, *Experimental Techniques*, by William C. Elmore, Swarthmore College, Swarthmore, Pa., and Matthew L. Sands, Massachusetts Institute of Technology, Cambridge, Mass. Deals with the new instrumentation techniques developed to take care of the unique problems of the atomic bomb laboratory at Los Alamos.

Volume 2, *Ionization Chambers and Counters*, by Bruno Rossi, Massachusetts Institute of Technology, and Hans Staub, Stanford University, Calif. Describes theory and development of the equipment required to detect and measure various types of radioactivity.

Division VI: UNIVERSITY OF ROCHESTER PROJECT. Editor, Donald R. Charles, University of Rochester.

Volume 1, *The Pharmacology and Toxicology of Uranium and Fluorine Compounds*, edited by Carl Voegtlin and Harold C. Hodge, both of the University of Rochester.

Division VII: MATERIALS PROCUREMENT PROJECT. Editor, Charles Slesser, New York Operations Office, Atomic Energy Commission.

Volume 1, *Preparation, Properties and Technology of Fluorine and Fluorine Compounds*, edited by Dr. Slesser. A comprehensive account of the unique development of fluorine chemistry and technology by the Manhattan Project. This work is becoming the basis of a whole new industry in the field of synthetic organic compounds, including saturated fluorocarbons which are virtually non-destructive.

Division VIII: MANHATTAN PROJECT. Editors, Clement J. Rodden, National Bureau of Standards, and Eugene W. Rabinowitch, University of Illinois.

Volume 1, *The Analytical Chemistry of the Manhatuan Project*, edited by Dr. Rodden. This important volume deals with the analysis of uranium and thorium.

FREE ISOTOPES SUGGESTED FOR CANADIAN INDUSTRY

A recommendation that radioisotopes be provided free for a year to any approved industrial research project was made last month at a two-day conference on industrial uses of radioisotopes in Ottawa, Canada. Trade Minister C. D. Howe made this suggestion at a meeting sponsored by the National Research Council of Canada and attended by many prominent Canadian scientists.

The conference included discussions on the following subjects: pulp and paper, chemical industries, food industries, oil and rubber, and miscellaneous industries; also physics and metallurgy. There were two exhibits, one on electronics, and the other on health precautions and the production of isotopes.

FIRST FRENCH PILE SET IN OPERATION

The first French nuclear reactor went into operation on December 15, according to an announcement by Frederic Joliot-Curie, high commissioner of the French atomic energy project. This uranium-oxide pile, located at Fort Chatillon, near Paris, is a low-energy pile, using heavy water as a moderator.

PITZER APPOINTED AEC DIRECTOR OF RESEARCH

Kenneth S. Pitzer, professor of chemistry at the University of California, Berkeley, has been appointed director of research of the Atomic Energy Commission. Dr. Pitzer replaces James B. Fisk, who resigned on August 27, 1948, to resume his duties as professor of applied physics at Harvard University. Dr. Pitzer, who will be on leave of absence from the University of California, will direct the AEC's research program in the physical sciences, and will supervise the administration of isotope production and distribution.

WAYMACK RESIGNS FROM AEC POSITION

W. W. Waymack resigned last month as a member of the United States Atomic Energy Commission. This is the first change in the make-up of the commission since it was formed in 1946.

Mr. Waymack, who resigned for "personal reasons," was to have held his position until 1950. In 1948, Congress extended the terms of each of the five commissioners for two years.

NUCLEAR TALKS TO BE GIVEN AT IRE CONVENTION

The 1949 national convention of the Institute of Radio Engineers will be held from March 7 to 10 at the Hotel Commodore and Grand Central Palace in New York. There will be a technical session on nucleonic instrumentation and a nuclear science symposium on March 8. The program for March 8 is presented below:

Tuesday afternoon, March 8, Nucleonic Instrumentation: *Industrial thickness gage employing radioisotopes,* by J. R. Carlin, Tracerlab, Inc.; *Design of a G-M counting tube of high counting rate,* by W. W. Managan, Victoreen Instrument Co.; *Electrometer tube and circuit,* by H. F. Starke, Raytheon Mfg. Co.; *Professional counter equipment for beta detection,* by William Bernstein, Brookhaven National Laboratory; *A high-voltage supplier for radiation measuring equipment,* by R. Weissman and Stewart Fox, Nuclear Instrument and Chemical Corp.

Tuesday evening, March 8, at 8:00 p.m., Nuclear Science Symposium, Ralph E. Lapp, Research and Development Board, chairman: *The fundamental particles,* by D. J. Hughes, Argonne National Laboratory; *Detection and measurement of nuclear radiation,* by H. L. Andrews, National Institutes of Health; *Effects of ionizing radiation on tissue,* by J. P. Cooney, Atomic Energy Commission; *Application of nuclear radiation to industry,* by J. R. Menke, Nuclear Development Associates, Inc.

AMERICAN TOBACCO CO. JOINS RESEARCH PLAN

The American Tobacco Company has become the sixteenth company which is cooperating in the $12,000,000 basic research program of the University of Chicago, according to an announcement by Vincent Riggio, president of the company. The company has become an industrial member of the Institute of Radiobiology and Biophysics for the next five years. Under this program industrial members confer informally with the scientists at work in the institutes (Institute for Nuclear Studies, Institute of Metals, and Institute of Radiobiology and Biophysics) and attend quarterly meetings at the university. Participating members may develop any industrial applications of ideas obtained from such meetings.

PENN DEDICATES RESEARCH LABORATORY

A nuclear research laboratory, costing $200,000, was dedicated last month by the University of Pennsylvania. The Department of Physics will use the new building to carry on research jointly with the Office of Naval Research. A 22-Mev betatron is housed in the laboratory.

VOLWILER TO HEAD ACS IN 1950

Ernest H. Volwiler, executive vice president of Abbott Laboratories, North Chicago, Ill., has been chosen president-elect of the American Chemical Society. He will head the society in 1950. The present president is Linus Pauling, chairman of the division of chemistry and chemical engineering in the California Institute of Technology.

BOOKS

RADIOACTIVE INDICATORS, THEIR APPLICATION IN BIOCHEMISTRY, ANIMAL PHYSIOLOGY, AND PATHOLOGY, by George Hevesy, Interscience Publishers, Inc., New York, and Interscience Publishers, Ltd., London, 1948, 574 p., $10.00. *Reviewed by W. F. Libby, Institute for Nuclear Studies and Department of Chemistry, University of Chicago*

The contributions of Professor Hevesy to the tracer field have of course been of paramount importance, so the present book has the ring of real authority throughout its length. The initial chapters are devoted to those general principles of radiochemistry concerned with the use of radioactive indicators and the remainder of the book is devoted to biological applications.

Chapter I, "Production of Radioactive Indicators," discusses the methods of producing radioactive indicators and gives in considerable detail satisfactory recipes for the important biological tracers.

Chapter II, "Radioactive Isotopes of Possible Interest in Tracer Work," is of a little more general nature, concerned primarily with the question of procurement of tracers, and discusses the offerings of the Atomic Energy Commission Isotope Division in some detail.

Chapter III, "Determination of Radioactivity," contains a summary of the methods found satisfactory, particularly in biological work, for the isotopes of biological interest. The remark is made in this chapter that measurement techniques are somewhat a matter of taste, each laboratory being disposed to favor its own counting arrangement. This certainly is a correct point of view. There frequently are a number of ways of accomplishing a particular measurement, and it is indeed a matter of taste as to which is favored. Chapter III is a good brief summary of a wide range of techniques. It also contains some useful decay tables for Na^{24}, K^{42}, and P^{32}, in which the fraction of the initial activity is given to four decimals as a function of time for some seven half-lives.

Chapter IV, "Atomic Interchange," is concerned with atomic interchange in general, and is a brief summary of the work that has been done. It certainly is not exhaustive, but is sufficient to this text, which is concerned primarily with the application of tracers to biology.

Chapter V, "Application of Isotopic Indicators in Chemical Analysis," contains a discussion of the method of isotope dilution analysis. This important technique is briefly but very clearly presented. It may be that certain readers would have appreciated a more detailed exposition of this material.

Beginning with Chapter VI and continuing to the end of the book, through Chapter XII, for over 400 pages of material, the subject is the application of tracers to biology. It appears that these pages contain the most exhaustive and expert presentation of the material on application of tracers to biology that has been published. Certainly the points of physical principles seem to be well in order and presented clearly and without error. The points of biology have been beyond the reviewer's information, but one has the general feeling that Dr. Hevesy speaks with real authority in this field as well.

Chapter VI, "Absorption, Distribution, and Excretion of Elements," containing some 93 pages, describes data for the following elements: phosphorus, arsenic, sulfur, selenium, chlorine, bromine, iodine, astatine, sodium, potas-

sium, calcium, strontium, radium, lead, antimony, bismuth, polonium, thorium, plutonium, iron, cobalt, manganese, copper, gold, zinc, inert gases and certain airborne fission products. It is, of course, abundantly clear from this chapter that much further work remains to be done to establish principal points. It is also equally clear that certain general behavior patterns exist for elements of similar chemistry and that, broadly, similarities in behavior exist for all elements. The data, of course, demonstrate clearly the characteristic of biological work so unsavory to physical scientists, namely the difficulty of controlling biological systems. It is fair to say that Chapter VI would be a very good introduction to a man contemplating research in the general field discussed in this chapter.

Chapter VII, "Application of Isotopic Indicators in the Study of Permeability of Phase Boundaries," contains a wide collection of topics all joined together by the general subject of the chapter. The comparison of the volumes of the system available to the alkali metal ions, the halogens, and water (by means of D_2O or tritium) is extremely interesting and must be of considerable importance to the biologist. This aspect of determinations of available space for the various elements in living animals is carefully and rather exhaustively presented, it being clear that the author considers it a matter of real importance. The data on the kinetic aspects of the permeability problem are extremely well presented. Again the variation of individual biological systems is apparent, but general trends are quite clear, and one has a feeling that this work must be of real importance in both fundamental biology and potentially in practical medicine. The reviewer has been told that the determination of blood volume by some of the methods Dr. Hevesy describes has already proved to be clinically useful in Europe.

Chapter VIII, "Turnover Studies," is devoted to the question of biochemical distribution of labeled chemicals, whereas the first two biological chapters, VI and VII, were devoted to the question of anatomical distribution. The chemicals studied include phosphorus-containing carbohydrates, phosphatides, nucleic acids, sulfur compounds, iodine and thyroid metabolism and a general section headed "carbon compounds." The chapter consists of about 150 pages of material, and describes a very large number of independent researches which the author has collected together into an intelligible entity. The reader is expected to have a considerable knowledge of biochemistry, and it was a little difficult for the present reviewer to understand a good fraction of this material, but despite the strangeness of it it was fascinating reading throughout.

Chapter IX, "Paths of Intermediary Reactions," is again devoted to biochemical mechanisms rather than questions of anatomical distribution. It is mainly concerned with the use of labeled phosphate, and is a very short chapter, only 5 pages.

Chapter X, "Skeleton Metabolism," is a straightforward presentation of the question of segregation of various injected elements in the body, principally phosphorus, though calcium, radium, lead, sodium, potassium, zinc, radiocarbon, the fission products and plutonium are treated also.

Chapter XI, "Application of Radioactive Indicators in the Study of Red Corpuscles," in many ways appears to the reviewer to be one of the most distinguished chapters in the book. One has the feeling about this subject that more progress has been made here than in other applications of tracers to biology. The story seems to be moderately clear and consistent, and the methods of investigation particularly apt and satisfactory for the problems.

Some 60 pages are devoted to this material.

Chapter XII, "Shortcomings of Radioactive Indicators," is the final chapter in the book. It consists of 8 pages, and contains the usual warning remarks about the chemical non-identity of isotopes. Five pages are devoted to noxious effects of radiations emitted by radioactive indicators. The reviewer felt that this section was somewhat too brief in view of the growing importance of this subject to workers in the field, and could well have been presented in more detail.

A special pocket envelope contained in the back of the book contains a very useful isotope chart, prepared by Dr. Segré and printed on an 18 in. × 48 in. sheet. The print is very clear so that all of the data are legible.

The book contains a few typographical errors, but has a pleasing balance between illustrations and printed material, the paper is good quality, and both an author and subject index, which appear to be quite exhaustive, are included.

It appears to the reviewer that the workers in biological fields will find this book indispensable if they are working with tracers, and highly valuable if they are not. The radiochemist, on the other hand, may not want to read the entire book, but certainly will find the first hundred pages of real value.

* * *

MILITARY AND POLITICAL CONSEQUENCES OF ATOMIC ENERGY, by P. M. S. Blackett, Turnstile Press, Ltd., London, 1948, 216 p. *Comments on the book and its author, presented below, are by Frederick R. Brewster, Chief, London Bureau, McGraw-Hill World News, based on a personal interview with Dr. Blackett.*

Center of a warm international controversy is the recently-published book, "Military and Political Consequences of Atomic Energy," by Professor P. M. S. Blackett, Britain's 1948 Nobel prize winner for physics and one of the world's most distinguished experimental physicists.

Professor Blackett is an iconoclast, and a realist. And full of moral courage, too, for he doesn't hesitate to attack the widely popular Baruch Plan for the control of atomic energy, now supported by a majority of the members of the United Nations' Atomic Energy Commission, even though his views run sharply counter to the official British and American policy.

Says Professor Blackett: "The Baruch Plan is not the generous gesture most people think it is. Instead, it is quite definitely more advantageous to America and the Western powers than to Russia, and Russia is fully justified in refusing to accept it because it would be damaging both to her military security and to the development of her resources of atomic power."

The natural reaction to such views is to abuse their author as pro-Russian, as talking the Communist "line." Frederick H. Osborn, U. S. deputy representative on the Atomic Energy Commission, assailed the book as a bit of special pleading for Russia; said Osborn in a speech at the Cambridge Union on November 22: "All the Soviet spokesmen have quoted Blackett. Mr. Vyshinsky in his last speech, quoted from Dr. Blackett's book some ten times." Mr. Osborn went on: "It is especially strange (that) a man brought up in the United Kingdom and its schools (should possess such cynicism), yet cynicism is the hallmark of this

book as it is indeed the hallmark of Soviet diplomacy. Only on the basis of such cynicism can intelligent men use such tendentious arguments, based on false premises. Through interminable months we have come to recognize such arguments as a basis for all Soviet thinking."

Mr. Osborn was speaking on a platform where he had originally requested a chance to debate Professor Blackett on the views in his book. But Blackett had politely declined: he is no debater, he told me, when I talked with him a few days previously. Nor is he a Communist. Even the Communists admit that his views don't go as far as theirs would—and most of the qualified reviews of his book (soon to be published in America by McGraw-Hill's Whittlesey House) concede that Blackett's views are logically worked out, rather than dictated by a predetermined concept.

Professor Blackett rather expected to be labeled a Russophile for the views in his book. "It's the natural reaction, nowadays," he told me, "to charge anyone who criticizes the official British or American foreign policy with being pro-Russian. Why even Dr. Evatt, the Australian, drew forth similar expressions when he recently challenged the Allied policy in Berlin." I gathered there was no personal resentment in Dr. Blackett's heart toward these slanders.

The essence of Blackett's case against the Anglo-American approach, which appears to be one of unyielding firmness on the basis set forth in the Baruch Plan, is that this proposition is based on absurd assumptions. Yet insistence on the framework of control it sets out—and wild talk about "forcing a show-down with the Russians now, before they get the atomic bomb"—is likely to precipitate a third World War that Blackett (among many others) is anxious to avoid.

Professor Blackett believes that there is less danger of a third World War in the next few years than is generally thought. "On one hand," he says, "it seems overwhelmingly to Russia's advantage to avoid a war; and on the other, America is unlikely to precipitate one, for a number of reasons." (These reasons are detailed below.)

But this uneasy balance must not be allowed to continue too long, he feels. "In a few years, after Russia has accumulated a stockpile of a few thousand bombs, her military strength (already very great in terms of the size and efficiency of her army) will be much enhanced. And although atomic bombs will bring no decisive results if used solely for area bombing of cities unrelated to military operations, they would be of great tactical value when used in conjunction with large-scale land operations."

For this reason, Professor Blackett feels that negotiations for a new basis of control of atomic energy must be resumed very soon. Else, Russia will hold too many of the trump cards.

But the present impasse in the Atomic Energy Commission does not promise much for such negotiations. The settlement between Russia and America which all the world hopes for must, according to Blackett, be based essentially on a bargain between the two states. "Both sides must make comparable sacrifices, and reciprocally receive comparable advantages *at all stages* (italics mine—FRB). If America continues to insist on treating atomic energy in isolation—and not as part of other weapons of mass destruction and along with conventional armaments and land armies as well—then clearly there will be no possibility of a bargain, until Russia has drawn more nearly even with America in the field of atomic energy."

It is difficult to condense Blackett's thesis in a few words. But it is a ring-

ing challenge to the complacency with which the Western powers have settled down stubbornly on the approach to atomic energy control embodied in the Baruch Plan, and have refused to examine it objectively to see whether it contained the seeds of full agreement. And his book is also a calming dash of cold realism to the hot-headed view that America, with the bomb, can talk as tough as she likes to Russia, brandishing the threat of sudden annihilation if Russia does not come to terms.

In essence, Professor Blackett calls for a re-examination of the two different viewpoints confronting each other at the United Nations' conference table.

The Russians (he argues) are faced with the threat from America's atomic bombs *now*—while the Russian threat to America of atomic warfare is still some years in the future. Consequently, Russia is understandably concerned in her political maneuvering with measures to remove the menace of the U. S. stockpile of atomic bombs as an immediate objective. America, on the other hand, not being immediately threatened, characterizes the long-range danger as the true danger she seeks to eliminate: that is, the rise of uncontrolled large-scale production of atomic explosives (i.e., fissionable materials) whether intended for military or for peaceful purposes.

The American conception has led them to propose a scheme of complete control of all atomic energy development by an international body free of the veto of any single power. The Russians, playing for time, have made counterproposals.

Professor Blackett thinks it is scarcely likely that either the Americans or the Russians seriously expected their respective proposals for control would be acceptable to the other. But by advancing the Baruch Plan, with its plausible fairness, American has won the initiative—and placed Russia in the difficult position of having to reject what Blackett terms "a speciously fair offer."

Mr. Gromyko, therefore, has done his best to retrieve the situation—so far unsuccessfully. But all of Russia's subsequent minor concessions have been directed toward the understandable Russian objective of delaying any decision until the real issues become clearer and Russia's bargaining position is improved.

Russia is given credit by Professor Blackett for having very good reasons for rejecting the scheme of control envisaged in the Baruch Plan. As stated above, these reasons are that it would be damaging to her military security and that it could have, and in all probability would have, led to a slowing down or even to a full stoppage of Russia's exploitation of atomic energy for industrial purposes.

Blackett gives the Russians the benefit of his calculations on this latter point; the U. S. and Britain, he says, who already have a high rate of energy production per head compared with Russia's much smaller rate, can afford to forego the advantages of atomic power development for a few years, and can advantageously stress the argument that atomic bombs are so dangerous that humanity should save itself from destruction by the bomb first and worry about power development later. Russia, he argues, with a keener need for more power resources, may well be justified in seeking to keep her own atomic energy development free of domination by a majority of the Western powers headed by America.

And, further, he points out in support of Russian refusal to accept the Baruch Plan of control, Russia's military security would be weakened by the timing of the several stages in this plan: America would keep her atomic bombs until a late stage of setting this control scheme in operation, and Russia would have no

firm assurance that when the stage was reached where the stockpile of bombs is to be disposed of, America might not raise some technical point to justify her retaining her bombs; meanwhile the Soviet Union would have thrown her land and economy open to inspection and so inevitably to military espionage.

In sum, the demand for complete security implicit in the Baruch Plan for control could not be satisfied within the next decade, Blackett thinks, without revolutionary changes in the political structure of the world. The U. S. has been proceeding on the confident assumption that these structural changes could be forced through *peaceably*—using to the full the threat of atomic warfare—or *by force* if necessary, without risking a long and devastating third World War.

While U. S. and Western Europe stand stubbornly on their insistence that the veto be removed from atomic energy control decisions, the U. S. is by no means willing to remove the veto from other activities of the Security Council.

The history of the last two years, says Blackett, shows that the world is not yet ready to accept peaceably the structural changes necessary—the relinquishment of national sovereignties, the abatement of national suspicions—for the introduction of the American plan of atomic energy control aimed at complete security. And, as Blackett points out in the rest of his book, they cannot be imposed by force without a disastrous war that would lay waste most of Europe and involve long and devastating civil war before reaching a conclusion. In other words, the atomic bomb is not an effective threat.

Why the Bomb is Overrated

Professor Blackett is no mere ivory-tower theorist on warfare. During the first war he served as a British naval officer for five years, before leaving the sea to take up his scientific studies. And during the second war he pioneered an almost completely new field—operational research—for, in turn, the Army's Anti-Aircraft Command, the RAF's Coastal Command, and the Admiralty. This experience in analyzing combat reports has been drawn on by him in his appraisal of the potential effectiveness of the atomic bomb.

To accomplish the equivalent destruction of the million and a third tons of bombs dropped on Germany during the war, some 400 atomic bombs of the most improved type would be required. And even this scale of slaughter and property destruction would be no more sufficient to defeat a potential enemy than it was to bring about the defeat of Germany—which was actually accomplished in the main through the land war.

Moreover, launching such an attack against a well-defended enemy would require considerably more than 400 bombers. Each atomic-bomb-carrying plane would have to be accompanied by many others; for such an armada bases would have to be prepared; and in the time required for such preparations Russia might well be taking additional precautions for her own defense and might very well develop atomic bombs herself.

A further factor which Professor Blackett pointed out to me in our conversation: never have the jet fighter planes of a nation's air defense forces had such a wide margin of speed-advantage over attacking bombers, as right now. He attributes a good part of the popular misconception of the possibilities of strategic mass-bombing attacks to the overlooking of this fact. By the time this margin is narrowed—by the development of jet-powered bombers—easily five years hence—the whole picture of atomic-bombing strategy will have changed.

A New Approach Is Needed

Professor Blackett has written his book in an attempt to induce a more realistic approach to international politics. He feels that there has been too much political maneuvering that has been divorced from sound military considerations. In particular, he feels that talk of forcing a showdown with Russia right now, and brandishing the threat of atomic annihilation, if she does not accept our principle of international control, is unrealistic and is endangering the large mass of the world's population and might precipitate a long, drawn out and bitter struggle over much of Europe and Asia, involving million-strong land armies vast military casualties, widespread civil war, and wholesale devastation.

This misguided thinking, he feels, undermines the whole logical basis on which America and the Western powers have taken their stand for atomic energy control.

The present agitation in public thinking—which has come to regard the international situation as involving two camps of enemies watching each other's preparations in hysterical anguish—is hardly conducive to clear thinking. Yet this hysterical anguish has been a major contributing factor to the deadlock in the United Nations' negotiations on control. It has led to the false belief on many sides that any control system which does not offer complete and perfect security is valueless.

A more realistic approach toward agreement on the American and British side—a realization that the "cold war" has not checked Russia but only incited her to more vigorous action toward solidifying her position—might, Blackett believes, bring about the sort of bargain between equals which could relieve the international tension.

If, in the new negotiations which must soon be forthcoming, atomic energy is not again treated in isolation; if, that is, atomic bombs are considered along with other weapons and armaments, Blackett sees the possibilities of an agreement acceptable to both Russia and America at an early date. This might involve the sort of armament limitation wherein each nation retains adequate supplies of those particular armaments it considers most useful to its particular situation. For instance, so many American atomic bombs and their carriers might be held to be the military equivalent of so many Russian divisions. Later, he says, it might be possible to distinguish between weapons of mass destruction and other weapons—but for the present it seems more hopeful to tackle the problem of general disarmament even though this means the continued existence in the world of some limited number of atomic bombs, rather than to attempt to abolish all atomic bombs while leaving other weapons uncontrolled.

Initially, Blackett feels, any control system for armaments should be based primarily on adequate inspection by an international inspectorate of all major armaments as well as atomic bombs, rather than on a form of international ownership and management. These latter themes, says Blackett, must be considered as a legacy of the fallacious belief in the decisive character of a single weapon.

At some later stage, however, he admits that if some form of world state was already in being or that relations between separate states were entirely friendly, the American plan of control of armaments through ownership and management might then become feasible. But, concludes Blackett, it is certain that "world government will not begin with world government in one weapon and one commodity, which was the essence of the majority report of the Atomic Energy Commission of the United Nations."

Major Classes of Uranium Deposits

URANIUM COMPOSES about 0.0004% of the earth's crust, but it occurs very sparingly in significant concentrations. There are five major classes of uranium deposits which are being exploited now or will be exploited in the future:

1. High-grade pitchblende-radium deposits [assaying better than 1% uranium oxide (U_3O_8) in quantity worth mining] **occurring as replacement bodies.** Where oxidized, the ore consists of autunite, carnotite, and other oxidation products of pitchblende, many of which are brightly colored. The better known deposits of this kind are Eldorado in Canada; Shinkolobwe in the Belgian Congo (from both of which the United States obtains uranium); and Joachimstahl and other deposits in the Erzgebirge district of Czechoslovakia and Germany which, according to newspaper accounts, Russia is exploiting. Deposits of this class may contain appreciable quantities of silver, copper, or cobalt.

2. Carnotite-type and roscoelite-type vanadium-uranium ores of the Colorado plateau. These closely related ore types are apparently important only in this country, but at best they are quite inferior to the high-grade ores as a source of uranium. These deposits occurring in flat-lying sandstones are under active development as part of the commission's program. Ore acceptable at AEC ore purchase depots contains a minimum of 0.10% U_3O_8, and payment is made for vanadium (V_2O_5) content in a ratio not exceeding 10 parts V_2O_5 to one part U_3O_8. By-product uranium from privately owned vanadium plants is also purchased by the commission.

3. Gold-uranium ores of the Witwatersrand, South Africa. Public announcement has been made of the occurrence of uranium as a very minor constituent of the gold-bearing Witwatersrand conglomerate. The prospect exists of future by-product uranium from the great gold mining industry of the Union of South Africa. The commission, through the U. S. Geological Survey, has been systematically examining all of the mill and smelter products in this country to discover if similar by-product possibilities exist here.

4. Uranium-bearing oil shales and other marine sediments. It has long been known that certain oil shales and other marine sediments, including phosphatic beds, contain very small quantities of uranium. Sweden, for example, has announced that she is building a small atomic pile and intends to derive uranium from her oil shales to feed this pile. According to published statements Swedish shale deposits containing many millions of tons of "ore" run around 0.02% U_3O_8. (These same geological formations extend northeastward up through Estonia and Leningrad.) By-product uranium from oil shale or phosphate industries may play a part in the development of atomic energy in different parts of the world. The AEC expects to exhaust every possibility of this character in the United States.

5. Miscellaneous other deposits. Pegmatites containing small amounts of pitchblende; placers containing a little uranium (generally as thorianite) along with monazite, and other ore types of as yet minor importance.

—From a release by U.S. Atomic Energy Commission

Atomic Energy Commission Publications

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706	The Total Disintegration Energy of Na^{24} (*1 p*)	.05
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Vol. I, No. 7.	Nuclear Science Abstracts (*53 pp*) (October 15, 1948)	.30
Vol. I, No. 8.	Nuclear Science Abstracts (*48 pp*) (October 30, 1948)	.30
Vol. I, No. 9.	Nuclear Science Abstracts (*47 pp*) (November 15, 1948)	.30

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Second-Semiannual Report of The United States Atomic Energy Commission	.10
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Recent Scientific and Technical Developments in the Atomic Energy Program of the United States (*Fourth Semiannual Report*) (July 1948)	.35

ABSTRACTS

CHEMICAL PUBLICATIONS

Measurement of carbon-14, J. D. Roberts, W. Bennett, E. W. Holroyd, C. H. Fugitt (Massachusetts Inst. of Technology, Cambridge) *Anal. Chemi.* **20,** 904–905 (1948). The determination of carbon-14 in organic compounds is carried out by first converting the compounds to carbon dioxide in a combustion train. Barium carbonate-C^{14} is then precipitated and its activity measured with a Lauritsen electroscope. The method is applicable to chemical mechanism studies where dilution factors are small and sensitivity may be sacrificed for simplicity.

Semimicro molecular still, I. A. Breger (Massachusetts Inst. of Technology, Cambridge). *Anal. Chemi.* **20,** 980–982 (1948). A semimicro molecular still is described which employs the falling film principle to eliminate continuous heating of the sample. This apparatus was successfully used to fractionate a small (4 g) quantity of a viscous oil obtained as a major conversion product from the bombardment of cyclohexanecarboxylic acid by deuterons.

Determination of nitrogen in organic compounds, S. G. Hindin, A. V. Grosse (Houdry Process Corp., Marcus Hook, Pa.), *Anal. Chemi.* **20,** 1019–1022 (1948). Nitrogen may be determined in organic compounds by a modification of the Dumas combustion method, in which the gaseous products are analyzed by means of a mass spectrometer and an inert gas such as neon is used as an internal standard. The method has the advantages of simplicity, good accuracy in the range of low nitrogen contents, and rapidity.

Rapid wet combustion method for carbon determination, A. Lindenbaum, J. Schubert, W. D. Armstrong (Univ. of Minnesota, Minneapolis), *Anal. Chemi.* **20,** 1120–1121 (1948). A wet combustion method is described for the determination of total and radioactive carbon content of organic samples. The method comprises oxidation of the sample under reduced pressure with the Van Slyke-Folch combustion mixture; absorption of the evolved carbon dioxide in barium hydroxide solution; and collection, washing, drying, weighing and β-activity measurement of the barium carbonate-C^{14}.

Search for elements 94 and 93 in nature. Presence of 94^{239} in carnotite, C. S. Garner, N. A. Bonner, G. T. Seaborg (University of California, Berkeley), *J. Am. Chem. Soc.* **70,** 3453–3455 (1948). Samples of carnotite, fergusonite, and hatchettolite were subjected to chemical treatment designed to isolate elements 94 and 93. The upper limits of the concentrations of these elements were established by neutron fission tests to be one part in 10^{10} of carnotite, one part in 10^9 of fergusonite, and one part in 10^9 of hatchettolite. The final fraction from carnotite gave a small alpha-particle counting rate which indicates the presence of one part in 10^{14} of 94^{239} in carnotite. The 94^{239} is probably formed as the result of the absorption by U^{238} of some of the neutrons emitted in the uranium spontaneous-fission process; the decay chain is $U^{239} \xrightarrow{\beta^-} 93^{239} \xrightarrow{\beta^-} 94^{239}$.

C^{14} tracer studies in the rearrangements of unsymmetrical α-diketones: phenylglyoxal to mandelic acid, O. K. Neville (Oak Ridge Natl. Lab., Oak Ridge, Tenn.), *J. Am. Chem. Soc.* **70,** 3499–3502 (1948). Phenylglyoxal labeled in the keto carbonyl group with C^{14} when treated with alkali yielded mandelic acid labeled with C^{14} in the α-position; this shows that the reaction proceeds by a shift of the aldehydic hydrogen atom. The similar reaction of α,α-dibromoacetophenone with aqueous alkali was also shown to take place without rearrangement of the carbon skeleton. Radioactivity measurements were carried out with a dynamic condenser electrometer. The preparation of C^{14}-labeled acetophenone, phenylglyoxal, mandelic acid, benzoic acid, and α,α-dibromoacetophenone are described in detail.

Separation of radium from barium by the use of an ion-exchange column procedure, E. R. Tompkins (Oak Ridge Natl. Lab., Oak Ridge, Tenn.), *J. Am. Chem. Soc.* **70,** 3520–3522 (1948). A solution containing 20 μg of radium, 20 mg of barium with Ba^{140} tracer, and 20 mg of strontium with $Sr^{89,90}$ tracer was passed through a column filled with colloidal agglomerates of Dowex 50 ion-exchange resin, and was then eluted with a 0.5*M* ammonium citrate solution (*p*H 7.8). The effluent was monitored by means of a thin-windowed flow cell facing a mica-windowed Geiger-Müller counter and recorder.

Fractions of the effluent solution were collected and aliquots were counted for α- and β-activity. It was found that the separation of strontium and barium, and of barium and radium, was nearly complete. It was concluded that the separation of radium from barium on a commercial basis could be much more easily effected by ion-exchange columns than by the presently used fractional crystallization methods.

Autoradiography of the thyroid gland, G. H. Bourne (London Hospital Medical College, Eng.), *Nature* **162,** 495–496 (1948). Autoradiography of the thyroid glands of mice was carried out by mounting serial sections of the thyroid lobes containing I^{131} directly on the emulsion of Ilford thin-film high-resolution plates. The sections were later stained with neutral red in order to obtain precise histological localization of the blackening of the emulsion. The localization of I^{131} in the colloid of the follicles was clearly shown. It was found that the smallest follicles concentrate the I^{131} more rapidly than the larger follicles, and that no part of the thyroid is more active than any other part in concentrating the radioiodine.

Selective development of fission tracks in an electron-sensitive emulsion, G. W. W. Stevens (Kodak, Ltd., Harrow, Middlesex, Eng.), *Nature* **162,** 526–527 (1948). Glass plates coated with a suspension of ammonium diuranate in gelatin were packed in contact with Kodak NT2a plates, and were exposed to neutrons from the Harwell nuclear pile. Development of these plates with special low-energy para-aminophenol developers made it possible to observe solid fission tracks readily distinguishable from the residual background; normal developers gave such high opacity in these plates that no tracks could be observed. Control plates which were left in contact with uranium showed alpha tracks only as solid lines when developed with normal developer, and as tenuous chains of grains with low-energy developer. With an even weaker developer, no alpha tracks at all could be distinguished on the control plates, but fission tracks could still be observed on the pile-exposed plates.

Decay of barium-139, L. R. Shepherd, J. M. Hill (Cambridge Univ., Eng.), *Nature* **162,** 566–567 (1948). The activities of Ba^{139}, produced by bombarding fused barium nitrate with 7 Mev deuterons in a cyclotron, were studied by means of a thin-lens β-ray spectrometer and by absorption and coincidence techniques. A Fermi plot of the β-spectrum indicates a maximum kinetic energy of 2.27 ± 0.02 Mev. Two conversion electron groups were found having energies of 126 ± 0.5 kev and 159 ± 2 kev; these groups correspond to the K and L electrons from the conversion of a γ-ray of 163 ± 0.5 kev in the product nucleus. The ratio of conversion electrons to β-particles is $5 \pm 1\%$. Most of the γ-radiation has a mass absorption coefficient of 1.38 cm^2/g corresponding to the 163-kev γ-ray. About 10% of the counting rate appears to be due to a harder 1.05 ± 0.1 Mev γ-ray.

Preparation of pure iron-59 of high specific activity, A. W. Kenny, W. R. E. Maton (Atomic Energy Research Estab., Harwell, Eng.), *Nature* **162,** 567–568 (1948). Hydroferrocyanic acid was irradiated in a nuclear pile (slow neutron flux 2.5×10^{10} neutrons/cm^2) for one month. Fifty percent of the total activity was extracted from the irradiated solid with dry, dilute ethereal hydrochloric acid. The ethereal extract was taken to dryness and digested with water. The aqueous extract contained at least 90% of the activity of the ether extract, and was proved by absorption data to be radioactively pure Fe^{59}. The specific activity of the Fe^{59} was about 1.5 mc/gm.

Ionization in liquid and solid argon, G. W. Hutchinson (Cambridge Univ., Eng.), *Nature* **162,** 610–611 (1948). Electrons were found to be charge carriers in ion chambers filled with liquid or solid argon. The largest pulses observed with liquid argon irradiated with γ-rays from radium C, using fields of 10,000 volts/cm, corresponded to complete electron collection. Bigger pulses were found with solid argon and fields greater than 13,000 volts/cm, but the effect disappears because of polarization. Electron multiplication in liquid and solid argon was also studied by means of a proportional counter; in the liquid, only ordinary sized pulses were observed, while, in the solid, multiplication greater than tenfold was observed although polarization was rapid.

Hydrogen peroxide and the indirect effect of ionizing radiations, T. Alper (National Physical Lab., Pretoria, South Africa), *Nature,* **162,** 615–616 (1948). Experiments with bacteriophage S13 indicates that deactivation of the phage in dilute

solution by ionizing radiation may be explained by assuming that the hydrogen peroxide formed acts as a specific poison.

Air-cored synchrotron, T. R. Kaiser, J. L. Tuck (Oxford Univ., England), *Nature* **162,** 616–618 (1948). A method is described for bringing electrons up to the extreme relativistic region in an air-cored synchrotron, which has the advantages of limited radial drift of electrons and a constant oscillator frequency. The frequency of the accelerating r-f field is made an integral multiple of the frequency of revolution of the electrons at injection, which takes place at the inside of the doughnut. The electron orbit is expanded by increasing the magnetic field; then the oscillator is blanked off until the equilibrium orbit shrinks to the inside. The r-f field is re-applied, and this sequence is repeated until the desired electron energy is reached. Experiments indicate that impulsive forces greatly in excess of the static ultimate strengths of the coil materials can be withstood; this is important since the upper limit of energy is set by the strength of the conductors.

The evolution of the universe, G. Gamow (George Washington Univ., Washington, D. C.), *Nature* **162,** 680–682 (1948). The evolution of the universe is discussed, starting with the hypothesis that the original state of matter was a very dense over-heated neutron gas originating from a universal collapse. Expansion led to neutron decay, followed by building up of more and more complex particles from the newly formed protons and remaining neutrons. This point of view leads to relative abundances of the elements which are in good agreement with observations.

. . . I. W. RUDERMAN

LIFE SCIENCE PUBLICATIONS

The use of radioactive iodine in the diagnosis of thyroid disease, S. Feitelberg, P. Kaunitz, L. Wasserman, S. Yohalem (Physics Dept., Mount Sinai Hosp., New York), *Am. J. Med. Sci.* **216,** 129–135 (1948). A method for measuring and recording isotopic iodine uptake by the thyroid gland is described. Applications of the method in representative cases of the disease are discussed.

Capillary permeability: Rate of transcapillary exchange of iron added to plasma as radioactive ferric beta$_1$-globulinate, L. Flexner, G. Vosburgh, D. Cowie, (Dept. of Embryol., Carnegie Inst., Washington, D. C.) *Am. J. Physiol.* **153,** 503–510 (1948). Of the iron of plasma 0.3 to 1% is exchanged per minute. Assuming that iron crosses the capillary wall as ferric beta$_1$-globulinate, it appears that the capillaries are at least one hundred times more permeable to water than to the globulinate. It appears that tagged ferric globulinate is acceptable for measurement of plasma volume in laboratory animals.

Turnover and distribution of phosphate compounds in yeast metabolism, E. Juni, M. Kamen, J. Reiner, S. Spiegelman (Dept. of Bacteriology and Immunology, Washington Univ., St. Louis, Mo.), *Arch. Biochem.* **18,** 387–408 (1948). Cells were incubated with labeled orthophosphate. They were then fractionated into acid soluble compounds, organic and inorganic, phospholipides, phosphoproteins and the two varieties of nucleic acids. The inorganic orthophosphate exhibited the most marked activity. Activity of all fractions reached saturated values far below those corresponding to complete equilibrium with exogenous phosphate.

The clinical use of radioactive iodine, S. Werner, E. Quimby, C. Schmidt (College of Physicians and Surgeons, Columbia Univ., New York), *Bull. N. Y. Acad. Sci.* **24,** 549–560 (1948).

Phosphate metabolism and the dissociation of anaerobic glycolysis from synthesis in the presence of sodium azide, S. Spiegelman, M. Kamen, M. Sussman (Medical School, Univ. of Minnesota, Minneapolis), *Arch. Biochem.* **18,** 409–436 (1948). The ability of the cell to esterify inorganic phosphate was suppressed greatly at azide concentrations which did not interfere with glucose metabolism. The exchange of internal and external phosphate as measured with P^{32} was also inhibited by the presence of azide. Fermentation sensitivity to poisons which inhibit triose phosphate dehydrogenase was decreased and fermentation sensitivity to fluoride was increased in the presence of azide. On the basis of these and other findings it is suggested that azide uncouples anaerobic oxidation from synthesis by means of a replacement reaction between azide and the acyl phosphate of dephosphoglycerate while the latter is

combined with phosphopherase. The resulting acyl azide, being unstable, would hydrolyze rapidly.

The distribution of radioactivity in the mouse following administration of dibenzanthracene labeled in the 9 and 10 positions with carbon-14, C. Heidelberger, H. Jones (Univ. of California, Berkeley), *Cancer* **1,** 252–260 (1948). Distribution of radioactivity in mice at various time intervals after administration of carcinogen was determined. The carcinogen was rapidly eliminated, largely through the feces with very little being absorbed. Rate of elimination and distribution pattern were dependent upon the mode of administration. Appreciable quantities of radioactivity were found in tumors produced several months after a single subcutaneous injection of dibenzanthracene. No effects were detected from the irradiation of the labeled carcinogen.

The metabolic degradation in the mouse of dibenzanthracene labeled in the 9 and 10 positions with carbon-14, C. Heidelberger, M. Kirk, M. Perkins (Univ. of California, Berkeley), *Cancer* **1,** 261–275 (1948). Dibenzanthracene is believed to be metabolized by the mouse into at least four substances. It is believed that the metabolic degradation described is merely a detoxication process unrelated to the initiation of cancer. Unchanged dibenzanthracene was found in tumors six to eight months after induction; this confirmed spectrophotometric work of other reseachers.

The antithyroid effect of certain foods in man as determined with radioactive iodine, M. Greer, E. Astwood (Joseph H. Pratt Diagnostic Hosp. and Tufts Med. School, Boston, Mass.), *Endocrinology* **43,** 105–119 (1948). Of all the foods tested, rutabaga was found to have the greatest antithyroid activity. Vegetables were more active than animal products. Cow's milk, beef liver and oysters showed some activity.

The inhibitory action of excessive iodide upon the synthesis of diiodotyrosine and of thyroxine in the thyroid gland of the normal rat, J. Wolff, I. Chaikoff (Univ. of California Med. School, Berkeley), *Endocrinology* **43,** 174–179 (1948). Far more diiodotyrosine was synthesized by rat thyroid after injection of 5 or 10 γ of iodide than was synthesized when 10 to 20 times these amounts were administered. The ratio of the specific activity of thyroxine to diiodotyrosine, its precursor, was decreased 2 to 4 times when the amount of iodide injected was increased from 5 or 10 γ to 100 γ, indicating that the conversion of diiodotyrosine to thyroxine was considerably slower when larger amounts of iodide were injected.

The effects of dietary protein on the turnover of phospholipides, ribonucleic acid, and desoxyribonucleic acid in the liver, R. Campbell, H. Kosterlitz (Marischal College, Univ. of Aberdeen, Scotland), *J. Biol. Chem.* **175,** 989–990 (1948). The turnover rates of phospholipides, ribonucleic acid, and desoxyribonucleic acid in rat liver at different stages of a protein-free regimen were obtained. During the first few days on the protein-free diet, the relative specific activities of phospholipide P and RNA P increased, while that of DNA P decreased. The total relative activities of phospholipide and RNA P were largely constant, indicating that the increased rate of renewal of these substances compensated for their loss from the liver. Apparently the total turnover of phospholipides and of RNA is determined by the metabolic requirements of the liver and within the limits of the experiment is independent of how much of these substances is present in the liver.

Ketone body formation from tyrosine, S. Weinhouse, R. Millington (Research Inst. of Temple Univ., Philadelphia, Pa.), *J. Biol. Chem.* **175,** 995–996 (1948). Tyrosine labeled in the beta carbon with C^{14} was incubated with rat liver slices and the acetoacetate formed was analyzed for isotopic content. Substantially all of the activity of the acetoacetate was in the alpha carbon. This is in accord with the suggested sequence of tyrosine degradation; tyrosine to *p*-hydroxyphenylpyruvic to homogentisic to acetoacetate.

The measurement of turnover of the various phospholipides in liver and plasma of the dog and its application to the mechanism of action of choline, D. Zilversmit, C. Entenman, I. Chaikoff (Univ. of California Med. School, Berkeley), *J. Biol. Chem.* **176,** 193–208 (1948). A comparison was made of the specific activity-time relations of liver cephalin, liver lecithin, liver sphingomyelin to alkali-stable and alkali-hydrolyzable phosphorus fractions. A liver fraction rich in glycerophosphate met the requirements for a lecithin precursor. The turnover of liver lecithin was increased by choline while those of plasma lecithin and plasma sphingomyelin were not. It is proposed

that choline stimulates the utilization of fats within the liver itself.

The turnover rates of plasma lecithin and plasma sphingomyelin as measured by the disappearance of their radioactive phophorus from the circulation, D. Zilversmit, C. Entenman, I. Chaikoff (Univ. of California Med. School, Berkely), *J. Biol. Chem.* **176,** 209–212 (1948). The rate of plasma lecithin turnover is more than 5 times as great as that of plasma sphingomyelin.

Studies on the metabolism of radioactive nicotinic acid and nicotinamide in mice, L. Roth, E. Leifer, J. Hogness, W. Langham (Los Alamos Scientific Lab., N. Mex.), *J. Biol. Chem.* **176,** 249–257 (1948). Nicotinic acid and nicotinamide labeled with C^{14} in the carboxyl group were used. Of the radioactivity fixed in the tissues, about 15% of the isotope in the carboxyl group is exhaled as CO_2. This is believed to be due to decarboxylation and also possibly to ring rupture followed by decarboxylation. The gross metabolism of nicotinic acid and nicotinamide in the mouse is identical.

The metabolism of plutonium in rats following intramuscular injection, K. Scott, D. Axelrod, H. Fisher, J. Crowley, J. Hamilton (Univ. of California, Berkeley), *J. Biol. Chem.* **176,** 283–293 (1948). Metabolic studies of Pu^{239} in its +3, +4, and +6 valence states were made. Pu was not absorbed to any extent from the gastrointestinal tract. The greatest degree of deposition and retention occurred in the skeleton. No significant differences were detected in the absorption by the body of the three different valence states of plutonium.

A study on the mechanism of "phosphotranferase" activity by use of radioactive phosphorus, B. Axelrod (Enzyme Research Div., U. S. Dept of Agriculture), *J. Biol. Chem.* **176,** 295–298 (1948). Using P^{32}-labeled nitrophenylphosphate and radioactive inorganic phosphate it has been shown that in the "phosphotransferase"-catalyzed transfer of phosphate from nitrophenylphosphate to methanol, the transported phosphate does not pass through the inorganic state.

Studies on the phosphorus metabolism of green algae and purple bacteria in relation to synthesis, H. Gest, M. Kamen (Mallinckrodt Inst. of Radiol. and Dept. of Chem., Washington Univ., St. Louis, Mo.), *J. Biol. Chem.* **176,** 299–317 (1948). Gross phosphate distribution is appreciably altered by experimental conditions prior to analysis of the organisms. Phosphate take-up is considerably greater in light than in dark for the organisms examined. There appears to be no constant proportionality between phosphate uptake and the over-all metabolic picture. Employing internally labeled organisms, it was indicated that cellular phosphate turnover and equilibration with exogenous phosphate were determined by a small fraction of the soluble cellular phosphate. Experiments involving the flow of phosphate between soluble and insoluble cell fractions show that light stimulates phosphate turnover. From these and other studies it is believed that ester phosphate may be formed as a result of light absorption, but there is no experimental evidence as to whether the esterification is or is not directly coupled with light absorption.

Hemoglobin synthesis from glycine labeled with radioactive carbon in its α-carbon atom, K. Altman, G. Casarett, R. Masters, T. Noonan, K. Salomon (Dept. of Radiation Biol., Univ. of Rochester, N. Y.), *J. Biol. Chem.* **176,** 319–325 (1948). α-carbon-C^{14}-labeled glycine is incorporated into hemin and globin of normal and phenylhydrazine-treated animals. The hemoglobin of phenylhydrazine-treated animals contains higher concentrations of C^{14} than that of normal animals. It is indicated that the partition of isotope activity between hemin and globin is essentially the same in normal and phenylhydrazine-treated animals.

Oxidation of glucose with radioactive carbon by normal and alloxan-diabetic rats, D. Zilversmit, I. Chaikoff, D. Feller, E. Masoro (Div. of Physiology, Univ. of California Med. School, Berkeley), *J. Biol. Chem.* **176,** 389–400 (1948). Carbon dioxide appears within the first 30 minutes in the expired air of both normal and alloxan-diabetic rats. The rate of conversion of plasma glucose to carbon dioxide by the alloxan-diabetic rat is not significantly different from the norm.

Inhibition of cleavage and P^{32} uptake in arbacia by d-usinic acid, A. Marshak, J. Harting (Tuberculosis Control Div., U. S. Public Health Serv., and Marine Biol. Lab., Woods Hole, Mass.), *J. Cellular Comp. Physiol.* **31,** 321–325 (1948). D-usinic acid markedly inhibits cleavage and P^{32} uptake with little effect on oxygen consumption of fertilized eggs of Arbacia.

The biologic effect of irradiation by radioactive iodine, B. Skanse (Thyroid Clinic, Massachusetts Gen. Hosp., Boston), *J. Clin. Endocrinol.* **8,** 707–716 (1948). Thyroid curves for doses of I^{131} ranging from 0.5 μc to 50 μc show that during the first 96 hours no physiologic change took place at these levels. The earliest effect was observed 144 hours after administration in the 50 μc group. Thyroids of chicks which received 1 μc of radioiodine did not change in growth or iodine concentration. Doses of 10 μc and 50 μc inhibited thyroid growth. Iodine concentration was not changed by a 10 μc dose but was decreased significantly in the 50 μc group. All irradiated animals responded to thyrotropic hormone as measured by an increase in thyroid weight and loss of iodine 16 days after administration of radioiodine.

The collection of radioactive iodine by the human fetal thyroid, E. Chapman, G. Corner, Jr., D. Robinson, R. Evans (Thyroid Clinic, Massachusetts Gen. Hosp., Boston), *J. Clin. Endocrinol.* **8,** 717–720 (1948). The human fetal thyroid does not collect administered radioactive iodine in the first 12 weeks of life. Increasing amounts are collected after the fourteenth week. Assuming radioiodine collection and functional activity are synonymous, the age of onset of physiologic activity of the human fetal thyroid can be approximated.

Dosimetric and protective considerations for radioactive iodine, J. Nickson (Sloan-Kettering Inst., Memorial Hosp., New York), *J. Clin. Endocrinol.* **8,** 721–731 (1948). Calculations of the amount of radiation received by the thyroid and the uncertainties involved in the calculations are discussed.

A study of the histopathology and physiologic function of thyroid tumors, using radioactive iodine and radioautography, B. Dobyns, B. Lennons (Thyroid Clinic, Massachusetts Gen. Hosp., Boston), *J. Clin. Endocrinol.* **8,** 732–748 (1948). With some exceptions, a parallelism has been found between the degree of function and the degree of cellular differentiation of adenomas. Adenomas have been found which have cellular hypertrophy and hyperplasia and which hyperfunction, and others which have cellular hypertrophy and hyperplasia which scarcely function at all. Adenomas functioning in excess of the remaining thyroid tissue occur with or without an elevation in the basal metabolic rate.

The use of radioiodine in the treatment of exophthalmic goiter, S. Haines, F. Keating, M. Power, M. Williams, M. Kelsey (Mayo Clinic, Rochester, Minn.), *J. Clin. Endocrinol.* **8,** 813–825 (1948). Of 40 patients with exophthalmic goiter treated with a single dose of radioiodine, 27 obtained good results, 8 obtained fair results and 5 obtained poor results.

The effect of total thyroidectomy on the function of metastatic thyroid cancer, R. Rawson, L. Marinelli, B. Skanse, J. Trunnel, R. Fluharty (Thyroid Clinic, Massachusetts Gen. Hosp., Boston), *J. Clin. Endocrinol.* **8,** 826–841 (1948).

Protection against radiation hazards and maximum allowable exposure values, K. Z. Morgan (Health Physics Div., Oak Ridge Natl. Lab., Tenn.), *J. Ind. Hyg. Toxicol.* **30,** 286–293 (1948).

Radiation hazards in industry, C. Williams (Harvard School of Public Health, Boston, Mass.), *J. Ind. Hyg. Toxicol.* **30,** 294–299 (1948).

Recovery and estimation of radioactive isotopes from biologic tissue—I. Gold, R. Dunn (Div. of Med. Physics, Univ. of California, Berkeley), *J. Lab. Clin. Med.* **33,** 1169–1176 (1948). A method is described for the recovery and estimation of radioactive gold from biologic tissue. Satisfactory results were obtained under a wide range of conditions.

The influence of estrogens on thyroid function as measured by uptake of radioactive iodine, K. Paschkis, A. Cantarow, W. Peacock (Jefferson Med. College, Philadelphia, Pa.), *Proc. Soc. Exptl. Biol. Med.* **68,** 485–486 (1948). Radioactive iodine uptake by rat thyroids was not changed after administration of estrogenic hormone or by ovariectomy.

Factors involved in the experimental therapy of metastatic thyroid cancer with I^{131}, L. Marinelli, J. Trunnel, R. Hill, F. Foote (Memorial Hosp., New York), *Radiology* **51,** 553–557 (1948).

Treatment of hyperthyroidism with radioactive iodine, E. Chapman, B. Skanse, R. Evans (Thyroid Clinic, Massachusetts Gen. Hosp., Boston), *Radiology* **51,** 558–563 (1948). The following observations were made. Radioactive iodine with a half-life of eight days is an effective single therapeutic agent. Myxedema was produced in but 4 out of 130 cases. Toxic effects of treatment with the eight-day isotope may be related to an exacerbation of the thyrotoxicosis which sometimes

occurs in the first week or two following treatment during which time stored thyroid hormone is released.

Clinical experience in diagnosis and treatment of thyroid disorders with radioactive iodine, S. Werner, E. Quimby, C. Schmidt (College of Physicians and Surgeons, Columbia Univ., New York) *Radiology* **51,** 564–578 (1948). Successful therapy resulted in 30 out of 34 cases after one and, when necessary, two doses. Causes of failure appeared to be related to inadequate dosage. No serious complications occurred.

General principles and purposes of tracer studies, C. Gemmil, *U. S. Naval Med. Bull.* **48,** 649–655 (1948). A general discussion is given of the use of tracers in biological work.

. . . BERNARD KANNER

PHYSICAL PUBLICATIONS

Radioactivity and mineral composition of soil, P. J. Hoogteijling, G. J. Sizoo (Vrije Universiteit, Amsterdam, the Netherlands), *Physica* **14,** 357–366 (1948). In sedimentary sand, as in the rocks from which they originate by physical pulverization, radioactivity is found to be concentrated in the heavy (zircon) mineral layer. In clays, which presumably are the result of chemical change, the radioactivity is not correlated with this zircon mineral. Correlation is found between radioactivity and potassium content of clays. It is concluded that for clays the radioactive elements are at least partly unbound by chemical change and spread over the whole material by adsorption onto the surface of small particles.

Ionization by alpha particles in liquids at low temperatures, A. N. Gerritsen (Kammerlingh Onnes Laboratory, Leiden, the Netherlands), *Physica* **14,** 381–424 (1948). The relation between an electric field and the ionization current in liquids at low temperature has been investigated in liquid nitrogen, hydrogen, helium, and argon. In nitrogen and hydrogen the linear dependence indicates that columnar ionization is not the case because of the corrective influence of diffusion on the ion distributions. Some deviations are observed in the cases of helium and argon. The ionization was produced by alpha particles from polonium.

Theory of oscillating absorber in a chain reactor, A. M. Weinberg, H. C. Schweinler (Oak Ridge Natl. Lab., Tenn.), *Phys. Rev.* **74,** 851–863 (1948). The response of a pile to a periodically varying absorber (which is oscillated back and forth inside the pile) is discussed. At low frequencies of oscillation the principal effect is to change the pile reactivity; the neutron intensity rises and falls, keeping the same shape as it had before insertion of the absorber. At high frequencies the positive and negative reactivity changes tend to cancel out, leaving a local depression in neutron intensity; this depression is propagated away from the absorber as a damped wave reflected at the pile boundary. The wave properties depend on the chain-reacting medium.

Measurement of neutron absorption cross sections with a pile oscillator, J. I. Hoover, W. H. Jordan, C. D. Moak, L. Pardue, H. Pomerance, J. D. Strong, E. O. Wollan (Oak Ridge Natl. Lab., Tenn.), *Phys. Rev.* **74,** 864–870 (1948). By moving an absorber back and forth in a pile, a local depression in neutron intensity is also caused to oscillate. The passage of the depression near an ionization chamber gives an oscillating signal proportional to the total absorption cross section of the sample. A gold absorber is used as a standard to determine the cross sections of unknown samples. A total cross section of 10^{-2} cm^2 can be detected. The signals due to absorption and scattering are out of phase, so that scattering cross sections much larger than the absorption cross sections can be subtracted.

Radioactive Br isotopes, L. L. Woodward, D. A. McCown, M. L. Pool (Ohio State Univ., Columbus), *Phys. Rev.* **74,** 870–875 (1948). Samples of selenium enriched in various isotopes were bombarded with protons, deuterons, and alpha particles in a cyclotron. Measurements were made on the various radiations emitted and, as a result, the characteristics of 2.4-day Br^{77} and 1.7-hour Br^{78} were determined. Measurements were also made on the beta and gamma rays emitted by 4.4-hour Br^{80}.

Argon 40 in potassium minerals, L. T. Aldrich, A. O. C. Nier (Univ. of Minnesota, Minneapolis), *Phys. Rev.* **74,** 876–877 (1948). A high sensitivity mass spectrometer was used to investigate the gas evolved from potassium minerals. The A^{40}/A^{36} ratio in the argon found was high compared with that of atmospheric argon. From this excess and from the amount

of K^{40}, a branching ratio for *K*-capture as compared with beta-emission of K^{40} can be calculated if the lifetime is known. Assuming a lifetime of 7×10^8 years, the ratio is at least 0.02. This method may be used to measure geologic age.

On the momentum distribution of the decay electrons from negative mesons, H. Primakoff (Washington Univ., St. Louis, Mo.), *Phys. Rev.* **74,** 878–882 (1948). The momentum distribution of decay electrons from negative mesons bound in the *K*-orbits of atoms is calculated on the assumption of decay into an electron and a neutrino of zero rest mass or a neutretto of 70 Mev rest energy. The spread in the momenta of decay electrons is $Z/137$ times the momentum of the decay electron from a free and stationary meson (Z is the charge of the nucleus). This is due to a "Doppler" effect, the electrons being emitted at various angles with the meson velocity, which is of the order of $Ze/137$ (e is the velocity of light). The electron momentum from a stationary meson is 50 Mev/c if the other particle is a neutrino, and 25 Mev/c if a neutretto.

A study of the radiations from columbium (95), rhenium (188), osmium (191), and osmium (193), C. E. Mandeville, M. V. Scherb, W. B. Keighton (Bartol Research Foundation, Franklin Institute, Swarthmore, Pa.), *Phys. Rev.* **74,** 888–893 (1948). The characteristic radiations of these isotopes were investigated by absorption and coincidence measurements. The beta-ray endpoints were determined by aluminum absorption, and maximum gamma-ray energy by coincidence absorption of secondary electrons in aluminum. Beta-beta, beta-gamma, and gamma-gamma coincidence rates were also measured.

On the life of self-quenching counters, S. S. Friedland (Memorial Hospital, New York), *Phys. Rev.* **74,** 898–901 (1948). A counter filled with argon and ethyl acetate was connected to a mass spectrometer and the mass spectrum taken after various numbers of counts. The amount of the parent molecule (quenching vapor) decreases and the amount of non-quenching vapor (decomposition products) increases linearly with the number of counts. A similar experiment with an argon-methane counter showed counter failure before the methane was appreciably diminished in amount, indicating that contamination of the insides of the counter by dissociation products limits the counter life.

A study of the deterioration of methane-filled Geiger-Müller counters, E. C. Farmer, S. C. Brown (Massachusetts Inst. of Technology, Cambridge), *Phys. Rev.* **74,** 902–905 (1948). The relation between counter life and characteristics of methane-filled counters was studied by mass-spectroscopic analysis of the counter gas. The major gaseous decomposition products were found to be hydrogen, ethane, ethylene, and acetylene, but their presence or the reduction in methane did not account for the counter failure. Heavy hydrocarbon deposit on the electrodes resulted in counter failure after 10^7–10^8 counts.

The beta-ray spectra of europium and tungsten, F. B. Shull (Randall Physics Lab., Univ. of Michigan, Ann Arbor), *Phys. Rev.* **74,** 917–925 (1948). The theory of a double-focusing magnetic beta-ray spectrometer is applied to a particular instrument whose design and operation are described. The beta spectrum of W^{185} was found to have an endpoint of 1.84 mc^2, and sources of 1–4 mg/cm² thickness showed deviations from linearity in the Fermi plot at about 100 kev. The gamma rays from 5 to 8-year europium were investigated using photoelectrons from a lead radiator.

Large-angle scattering of Na^{24} gamma-radiation, E. Pollard, D. E. Alburger (Yale Univ., New Haven, Conn.), *Phys. Rev.* **74,** 926–932 (1948). Scattering of 1.38 and 2.76 Mev gamma-radiation from Na^{24} has been observed at 135° using various scatterers. Components due to Compton scattering (at about 200 kev), and positron annihilation (following pair production) at 500 kev were observed. A third component between 1.1 and 2.8 Mev was found, partly, but not wholly due to brehmsstrahlung. It is not sharply resonant nuclear scattering, as comparison of Mg and Al scattering shows; the lack of sharp resonance shows that the levels in Mg^{24} are less than 0.01 ev wide.

The natural abundance of isotopes of stable elements, J. R. White, A. E. Cameron (Tennessee Eastman Corp., Oak Ridge, Tenn.), *Phys. Rev.* **74,** 991–1000 (1948). Determinations were made of the natural isotopic abundances of 24 elements. Nier-type, 60° mass spectrometers were used, ion currents being measured with a potentiometer, and different masses focused by varying the magnetic flux in the spectrometer. Each measurement series represents from 15–300 determinations of abundance ratio.

Deuteron-induced reactions, D. C. Peaslee (Massachusetts Inst. of Technology, Cambridge), *Phys. Rev.* **74,** 1001–1013 (1948). The reactions induced by deuterons of 2–15 Mev were studied to find the variation with energy of the *d-p* and *d-n* cross sections. The observed *d-p* excitation curve is found to be due, in all but the lightest elements, almost entirely to the stripping process at all deuteron bombarding energies. The same is true for *d-n* reactions at or above 10 Mev, with neutron and proton roles interchanged. Above the barrier height of the target nucleus, the *d-p* cross section decreases because of competition of the *d-n* reaction. For a given target, the ratio of *d-p* to *d-n* cross section is greater than one at energies comparable with the barrier, decreasing to approximately one as the energy becomes large. Comparison with experimental *d-p* cross sections shows good agreement.

A quantitative determination of the magnetic moment of the neutron in units of the proton moment, F. Bloch, D. Nicodemus, H. H. Staub (Stanford Univ., Calif.), *Phys. Rev.* **74,** 1025–1045 (1948). The ratio of neutron to proton magnetic moments has been accurately determined by simultaneous determination in the same homogeneous magnetic field of their Larmor precession frequencies. The ratio of these frequencies will then be that of the magnetic moments. The frequencies are determined by nuclear induction (for the protons) and by the non-adiabatic transitions of a polarized neutron beam. The value of the ratio is $|\mu_N|/\mu_P = 0.685001 \pm 0.00003$.

On nuclear dipole vibrations, M. Goldhaber (Univ. of Illinois, Urbana), E. Teller (Univ. of Chicago, Ill.), *Phys. Rev.* **74,** 1046–1049 (1948). The behavior of some photo-neutron and photo-fission reactions indicates a high-frequency resonance behavior unlike ordinary nuclear resonance and analagous to the "rest-strahl frequencies" of polar crystals. The gamma rays cause a vibration consisting of motion of protons in one direction and neutrons in the other—a "dipole vibration" of high frequency because of the strong binding between associated neutrons and protons. This will give a resonance for the gamma-ray absorption cross section, also giving rise to similar maxima for several nuclear processes of which gamma absorption is the first step. The estimated frequencies are in good agreement with experimental results.

Coincidence experiments on Sc^{46}, Ga^{72}, Au^{198}, Rb^{86}, E. T. Jurney (Indiana Univ., Bloomington), *Phys. Rev.* **74,** 1049–1052 (1948). Gamma-gamma and beta-gamma coincidences were investigated in these four isotopes. Gamma-gamma correlation was found in only the first two. Beta-gamma coincidences established that the beta-ray spectra of Sc^{46} and Au^{198} are simple, while those of Ga^{72} and Rb^{86} are complex. Absorption measurements were used to determine gamma-ray and maximum beta-ray energies.

Contributions to the nuclear processes induced in magnesium by polonium alpha-particles, A. Szalay, E. Csongor (Univ. of Debrecen, Hungary), *Phys. Rev.* **74,** 1063–1070 (1948). A hemisphere of magnesium was bombarded from the center by alpha particles from a polonium source. A loop counter of hemispherical shape was used to determine the excitation function for the process $Mg^{25}(\alpha,p)Al^{28}$, counting the beta rays from Al^{28}. The Mg hemisphere contained carbon dioxide at a pressure sufficient to reduce the alphas homogeneously to the desired energy. The excitation function and absorption of the gamma radiation induced by the bombardment were also investigated. They indicate that the gamma radiation probably comes from the reaction $Mg^{25}(\alpha,n)Si^{28}$.

A study of cosmic-ray bursts, H. S. Bridge, W. E. Hazen, B. Rossi, R. W. Williams (Massachusetts Inst. of Technology, Cambridge, Mass.), *Phys. Rev.* **74,** 1083–1102 (1948). An ionization chamber and its operation is described in connection with other ion chambers and a cloud chamber to study the nature of the cosmic-ray events responsible for the production of bursts. It was found that at mountain altitudes 98% of the ionization pulses in an unshielded counter are caused by nuclear disintegrations and 2% by air showers. Nuclear disintegration produces heavily ionizing particles of high energy. These disintegrations are produced mainly by non-ionizing radiation—not photons but possibly neutrons. The radiation producing the disintegrations is reduced to $1/e$ times its value by 12 inches of lead.

Sea-level latitude effect of cosmic radiation, P. A. Morris, W. F. G. Swann, H. C. Taylor (Bartol Research Foundation, Franklin Institute, Swarthmore, Pa.), *Phys. Rev.* **74,** 1102–1105 (1948). The variation in intensity of the total and hard components of cosmic radiation was

measured with a Geiger counter telescope from Rio de Janeiro to Boston. The hard component varied by 5.32 ± 0.46% from high latitudes to the magnetic equator; the soft component 4.46 ± 0.61%; the total radiation 5.04 ± 0.55%.

Line shapes in nuclear paramagnetism, G. E. Pake, E. M. Purcell (Harvard Univ., Cambridge, Mass.), *Phys. Rev.* **74,** 1184–1188 (1948). Various descriptions of the width and shape of nuclear paramagnetic resonances are compared. The difference between two dispersion curves based on the Lorentz shape function and a Gauss absorption curve is given, with experimental examples of each.

Theoretical design of linear accelerator for electrons, W. Walkinshaw (Atomic Energy Research Estab., Malvern, England), *Proc. Phys. Soc.* **61,** 246–254 (1948). A circular waveguide, with a phase velocity less than that of light and corrugations in the outer wall (to store magnetic energy), is described and theoretically analyzed. The dependence of phase velocity on frequency has been experimentally checked. The motion of electrons injected into a traveling wave is considered, and numerical design data is given suitable for designing an accelerator tube for any arbitrary power and chosen variation of phase velocity with wavelength.

Traveling wave linear accelerator, R. B. R.-Shersby-Harvie (Atomic Energy Research Estab., Harwell, England), *Proc. Phys. Soc.* **61,** 255–270 (1948). The general principles of the traveling-wave accelerator are described and some properties of the corrugated waveguide given; in particular, the maximum energy obtainable for electrons in such guides is found. Limits of efficiency are also given. Above 1 Bev some advantages are the linearity of cost with output energy, the small radiation loss, the short path (reducing vacuum problems), and the ease of obtaining an external beam. Focusing problems are also investigated.

Experimental work on corrugated waveguides and associated components for linear electron accelerators, L. B. Mullett, B. G. Loach (Atomic Energy Research Estab., Harwell, England), *Proc. Phys. Soc.* **61,** 271–284 (1948). The experimental work carried out on corrugated

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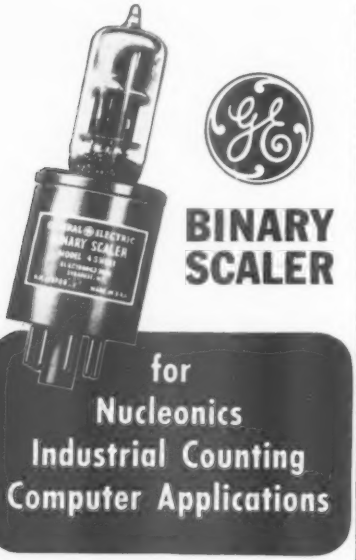

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waveguides for electron accelerators is described. The optimum number of corrugations was investigated, as were feed problems for various types of guide, using "annular" and "door knob" feeds. Experimental results follow the theory.

Effect of azimuthal inhomogeneities in the magnetic field of a betatron or synchrotron, F. K. Goward (Telecommunications Research Estab., Malvern, England), *Proc. Phys. Soc.* **61,** 284–293 (1948). A small axial disturbing field varying with azimuthal angle (which can be analyzed into a Fourier series) causes a forced oscillation of the electron. The oscillation is analyzable into frequencies which are multiples of the rotation frequency. Some examples are considered in relation to the effect on an injection of electrons into the machine. The possibility of ejecting the electron beam by use of a "step field" is investigated.

Coincidence circuit of medium resolution, H. L. Shultz, E. Pollard (Yale Univ., New Haven, Conn.), *Rev. Sci. Instr.* **19,** 617–620 (1948). A coincidence circuit of variable resolving time (0.01–0.4 microseconds) for use in the region of medium resolution, where intensities are low, is described for biased-diode level selectors. Experiments were conducted to determine the coincidence rate caused by particles passing through two separated counters as the resolution was varied. Delays and time fluctuations in the operation of counters were investigated; it was found that excessive statistical fluctuation in operation time limits the use of proportional counters for fast coincidence work.

Electrostatic deflection of a betatron or synchrotron beam, E. D. Courant, H. A. Bethe, *Rev. Sci. Instr.* **19,** 632–637 (1948). The method of removing the beam to the outside of a circular accelerator as here considered consists first of an expansion in the orbit by a sudden decrease of the magnetic field in the orbit region which causes the electrons to spiral outward. The resulting spray of electrons is reconcentrated into a beam by a strong electric field directed radially inward. The pitch of the spiral must be large enough for the insertion of the electrodes; this pitch depends on the change in magnetic field. The angular divergence of the final beam depends on the extent and intensity of the electric field.

A counter for low energy ionizing particles, H. C. Thomas, N. Underwood (Vanderbilt

(Continued on page 88)

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Univ., Nashville, Tenn.), *Rev. Sci. Instr.* **19**, 637–639 (1948). A counter has been devised which consists of several semi-cylindrical electrodes set parallel to each other with central wires connected. This gives a shallow sensitive volume and reduces background, while the solid angle subtended by the source is large. Absorption is reduced by having the specimen within the counter, which is filled with helium gas circulating through the chamber at atmospheric pressure and which has an operating voltage of 1600–1800 volts. The specimen is introduced into the sensitive volume by a turntable arrangement, after exposing it first in a preliminary helium-filled chamber.

Routine use of ionization chamber method for C^{14} assay, C. D. Janney, B. J. Moyer (Univ. of California, Berkeley), *Rev. Sci. Instr.* **19**, 667–674 (1948). An ionization chamber connected to an electrometer and its auxiliary apparatus is in regular use for the routine analysis of samples obtained from biological tracer experiments. The sample is analyzed in the form of CO_2 gas, and specific activities as low as 10^{-9} curies per gram can be analyzed. The sensitivity for total activity is 5 times and that for specific activity 15 times greater than a mica window counter, though the chamber filling requires somewhat longer.

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